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THE ECONOMICS OF COMMERCIAL-MILITARY INTEGRATION AND DUAL-USE TECHNOLOGY INVESTMENTS

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PREFACE

Since October 1992 the Institute for Defense Analyses (IDA) has assisted the Advanced Research Projects Agency (ARPA) with economic advice and recommendations regarding the Technology Reinvestment Project (TRP) under the task entitled "The Economic Impacts of Technology Investments." The purpose of the TRP is to promote integration of the commercial and military industrial bases to improve the affordability of weapons and systems while also contributing to the commercial competitiveness of U.S. industry through dual-use technology investments.

Earlier versions of this paper focused primarily on TRP dual-use investments to the exclusion of other Department of Defense (DoD) efforts. During the paper's long evolution, it became clear that DoD was engaged in other, non-TRP dual-use activities designed to increase the degree to which commercial industry may be relied upon to meet the needs of the military. For this reason the final version of the paper addresses the broader topic of dual-use technology investments and commercial-military integration as they pertain to meeting overall national security needs, and the conclusions and recommendations presented herein should be seen as generically applicable across all such DoD efforts.

The authors would like to extend their warmest appreciation to the reviewers of this paper for their significant effort to improve both its content and organization. Special thanks go to Bruce Kramer (National Science Foundation), Carl Ray (NASA), Ruth Haines and John Redman (National Institute of Technology and Standards), and Tom Frazier, David Graham, Andrew Hull, David Markov, Frederick Riddell, and Karen Richter (IDA).

CONTENTS

Appendixes

LIST OF ILLUSTRATIONS

FIGURES

TABLES

EXECUTIVE SUMMARY

While the notion of relying on the commercial industrial base for the needs of the military is gaining new currency in the face of falling defense budgets, improved commercial technology, and accelerated innovation, this notion was once eschewed by DoD as a criticism of its practices. During the Cold War, defense technologies became increasingly specialized to offset the numerical inferiority of U.S. and Western Alliance forces compared with those of the Warsaw Pact, China, and other nations. As a result, the United States evolved two separate and distinct industrial bases—one catering to the needs of the military, the other fully engaged in domestic and global private sector commercial market activities. Today, with the Cold War over, political, military, and industry leaders are seeking anew to operationalize broad, and at times "fuzzy," principles concerning commercial-military integration (CMI).

The gains that would accrue to the nation by recombining the commercial and military industrial bases are being actively debated, most recently in influential reports from the DoD Defense Science Board, the Center for Strategic and International Studies, the Carnegie Commission, and the Office of Technology Assessment. Still missing from the policy discourse, however, is a rigorous theory of CMI—a framework for explaining why it occurs where it does; why it does not occur more (or less) frequently; what forms it is likely to take; how to encourage or cultivate it; or even how to measure the degree to which it takes place.

A subtopic of this policy discourse—the use of dual-use technology investments to pursue industrial base integration—is the focus of this paper. The discussion centers on two related areas: 1) the economic and institutional issues involved in achieving CMI, conceptual and practical limitations of CMI, and how CMI should be viewed from a national security perspective in an increasingly globally integrated economy; and 2) the intellectual and practical issues involved in choosing among technology investments and assessing their benefits. Together these lines of inquiry result in a set of recommendations for constructing a robust approach to public policy-making to take the greatest advantage of defense dual-use investments for national security purposes.

PART 1: THE ECONOMIC FOUNDATIONS OF COMMERCIAL-MILITARY INTEGRATION AND DUAL-USE TECHNOLOGY INVESTMENTS

Within a changing environment shaped by rapid innovation, classifying the "dual-usefulness" of new technologies and their applications involves exploring dynamic interrelationships, beginning with scientific discovery and extending through the manufacture and life-cycle support of finished "products." In some cases, military requirements cannot be met by commercial industry or they may be inconsistent with commercial needs and practices. For instance, if the warning time prior to a conflict is short, the quantity of newly produced high technology weapon systems that will be available will not be significant under a regime of peacetime production. This means that more traditional approaches to stockpiling and maintaining materiel reserves will continue to be central to national security.

Instances where commercial capabilities and military requirements may be mutually satisfied, however, offer significant opportunities for DoD to leverage private sector investments to speed technology developments and improve affordability through market economies. To embark on a dual-use technology investment program that will realize CMI, DoD needs to change its approach to procurement and technology investment, incorporating greater flexibility. Such changes are necessary to accommodate the considerable variance among the possibilities that CMI represents. For instance, at one extreme, complete CMI could be characterized as commercial and military products employing identical production processes and being sold at comparable, competitively set market prices. This would be the same as purchasing all military requirements "off-the-shelf," an unlikely outcome even in the long run. At the other extreme, absence of CMI would be much like "business as usual" today—military products requiring practices and production techniques that have little in common with those of the commercial world.

The branch of economic theory that deals with enterprises seeking to produce different products from a common resource base is known as "multi-product production" or "co-production." This framework is useful in explaining the likely interaction between government and industry when seeking to pursue CMI goals. For instance, with co-production the government needs to know a firm's profits (and costs) under a hypothetical scenario that may never be observed. It also needs precise information about the cost structure of the firm (in particular the interaction between commercial and military goods and, therefore, how to allocate shared costs). From the government's point of view, and in particular that of DoD, co-production offers significant advantages since it promises to leverage commercial capabilities for military purposes. However, there are also issues surrounding the notion of "fair" pricing to the government, as well as complexities which arise regarding the coordination of requirements between the private and public sectors in the development, planning, and execution phases for new products.

Although many have posited significant potential for spinning off military technologies for commercial use, today most military technologies have few if any commercial analogs or applications. In fact, future investments in commercial technologies by the private sector are expected to be increasingly relevant for military applications; thus, spin-on is the more likely route for CMI. However, because commercial enterprise is rapidly becoming globally integrated, entwining commercial and military technologies introduces new issues regarding the domestic producibility of weapons systems and the international proliferation of advanced military capabilities.

In the context of CMI and dual-use technologies, "globalization" is a process of integration where the research, development, engineering, production, and marketing of military equipment, systems, and their components, including dual-use products, increasingly occurs across national boundaries worldwide. It is made possible due to the confluence of four tenets upheld by the international community: (1) permissive political regimes, (2) cheap, unfettered transportation, (3) high-capacity telecommunications, and (4) flexible business practices. Under a global production regime, weapon system designs are not the responsibility of one or a small set of firms, but are dispersed worldwide to take advantage of technical specialties of many participants. This also occurs for fabrication, assembly, and research and development activities. As a result, there are increasing numbers of cross-border collaborative business relationships in the form of foreign sourcing, cross-border business alliances, and foreign direct investment. But even under such a highly agile production regime, the ability of one or more firms to "dominate" vital market segments and use derived market power to distort resource, product, or process availability remains. To comprehend the national security implications of the globalization of commercial business enterprises one needs to understand the interaction of commercial and defense production activities as well as the institutional nature of industrial globalization.

We conclude that, to provide for national security in a global economy, the U.S. military must build upon world-class commercial capabilities wherever possible, including activities which offer unique, non-commercially available capabilities as quality multipliers. Commercial capabilities properly leveraged will lead to more affordable military systems, and at the same time will free-up budget resources to pursue specific military applications.

PART 2: CHOOSING DUAL-USE INVESTMENTS TO PROMOTE COMMERCIAL-MILITARY INTEGRATION

Over the past two centuries the economics profession has repeatedly explored how to rank preferences among different sets of social choices. The result has been a set of formalisms and theorems that today comprise the "theory of choice," which seeks to uncover the logical foundations of "rationally" choosing among alternatives or sets of alternatives. We extend that theory here to help understand how to choose technologies and technology support activities for investment.

One important principle is that selecting among projects based solely on technical measures, even when such measures are in common, generally leads to ambiguous results. Selection activities that rely solely on technical merit, therefore, employ so-called experts who must make informed judgments in order to come to closure. Technical characteristics are not, however, the only possible evaluation dimensions of a source selection processes, particularly when commercial applications are involved.

In the private sector, the monetary requirements to carry out a project, and the expected returns, are also a basis on which to judge and rank. Such financial considerations form the basis for private sector assessments of a project's "private rate of return." Here the issue is the perceived value of the project relative to its funding requirements and risk. This, in turn, reduces to an evaluation of projected profit streams and investment costs adjusted for risk. The two quantitative measures commonly used to rank financial returns are net present value (NPV, also termed "discounted cash flow") and internal rate of return (IRR). Reducing all investment decisions to simple NPV or IRR is what allows comparison of "non-financial" investment projects of all types with pure financial risks such as stocks, bonds, and commodities.

The literature on "financial" methods of technological choice offers two different approaches to making "sound" decisions on R&D investments. A strategic management perspective deals with the importance of the innovation process as it pertains to the overall management of competitive business enterprises and its ability to confer a competitive "edge." The second approach involves detailed techniques that may be used to evaluate and compare different technology and R&D investment possibilities." Such models include simple cost-benefit ratios, applications of linear programming, portfolio analysis techniques, group decision-making paradigms, and structured hierarchy processes.

Underlying the "simple" economics of technology investments are a whole host of issues that must be addressed to offer the quantitative comparisons useful to making business decisions:

- How easily appropriable is a technology expected to be?
- Is there a clear path to a commercial or defense market?
- How should intellectual property be handled?
- How should "qualitative" technical risks be quantified?
- What are the opportunity costs of forgoing an investment?
- Should risks be pooled or shared?

Regardless of the degree of possible quantification undertaken with such financial indicators, choosing technology investments continues to depend largely on the experience of investment managers. We observe that regardless of the attractiveness of the "numbers," successful technology investment managers rely heavily on their experience and accumulated knowledge of a technology, its prospects, and the marketplace to decide upon long-range activities leading to new products and processes.

In many cases, however, the private sector is not interested in undertaking a project because its "appropriable" rate of return is unattractive or it does not have proper corporate fit. This does not necessarily mean that it is unattractive to society at large—the *net* importance of an investment for society as a whole, taking into account all benefits and costs, may be disproportionately larger or smaller than for private individuals.

In judging the social worth of investments, two approaches are in general use to *retrospectively* assess the relative significance of a project for society. Econometric studies deal with improvements in productivity and output achieved due to a particular technological change. Social net surplus studies calculate overall net benefits including consumer savings and job formation or loss.

Econometrics is the quantification of stochastic relationships based upon observations which are purported to be evidence supporting or refuting an economic proposition. At best we can take econometric and other approaches to estimating the impacts from "progress" as quantified bodies of evidence of the importance of technological change to economic growth and productivity. If we believe that "the past is prologue," then such evidence may be used to structure public policies to take advantage of the potential benefits from technological progress, but this in no way gives us a deterministic tool for choosing investments or projecting their impacts.

At the level of the firm, a host of studies have been sponsored to assess the private and social rates of return for particular innovations. While econometric techniques may be used for such assessments, in the mid-1970s an approach similar to cost-benefit analysis became fashionable. These net social surplus techniques are used to assess changes in social welfare based on relatively simple notions of economic surplus.

We conclude that despite the significant amount of analysis of the economics of technological change, to date there is still no comprehensive, workable economic theory for *ex ante* estimating the precise impacts from technological change on the economy useful for focusing R&D investments, although available empirical evidence, deduction, and inference appear to suggest strong linkages.

PART 3: SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

CONCLUSION: **Commercial-Military Integration (CMI) is a natural and logical outgrowth of the rapidly increasing capabilities of private sector, commercial technologies worldwide.**

In Part 1 of this paper we argue that in recent years many military-unique technologies have emerged, leading some to conclude that the relevance of commercial technologies to the military is in the process of disappearing. However, this conclusion is inconsistent with recent policies that seek to maximize declining defense budgets through affordable weapon systems that make use of commercial-sector capabilities. According to these policies, in the same way that we moved from spin-off to militarily unique systems in the Cold War, we will move from militarily unique to spin-on systems now by promoting an integration of the military and commercial industrial bases (CMI). Understanding what types of dual-use technology investments will lead to successful industrial base integration, and which are militarily attractive but not commercially viable, is key to formulating a DoD dual-use investment strategy. In fact, there will always be an important need for some military-specific technology development for state-of-the-art weapon systems and associated production techniques.

CONCLUSION: **Achieving CMI will require significant effort on the part of the Department of Defense to bring its procurement and acquisition systems**

"business practices" into line with commercial norms. The role of dual-use investments in this context is to demonstrate the potential benefits for both commercial and defense firms who choose to serve both sectors.

In order to receive more militarily useful technologies from commercial industry, the needs of the defense community must somehow become aligned with commercial production goals. Attending this process is the issue of the appropriate role of the public sector in making the best use of industry for national security purposes in the absence of the immediate purchase of weapon systems. CMI technology investment policies must therefore be formulated to provide measured stimuli that are in harmony with existing market incentives and used to demonstrate the potential "synergies" that would yield benefits in both commercial and defense activities.

CONCLUSION: **Dependence on an integrated industrial base gives rise to new sorts of dangers to national security. Primary among these is the increased availability adversaries will have to technologies incorporated into U.S. military systems. In addition, a host of problems may result from the increasing proximity of commercial and military needs that will make defense expenditures a *de facto* part of the national welfare equation. The Department of Defense will need to improve its understanding of commercial technology and business developments in order to counter potentially threatening activities by transnational firms and to prevent the diversion of its resources for purposes other than national security.**

While promoting CMI, DoD must remember that "unifying" the commercial and military industrial bases will produce an environment where commercial advances will become increasingly central to national security. Correspondingly, the diversion of national resources for defense may be seen less as a drag on overall economic growth and more as a requirement for commercial endeavor. The prevalence of this perception will correlate with the success of CMI—future difficulty in separating commercial costs and benefits from defense technology investments will begin to cast such expenditures as socially beneficial. At all costs, DoD must avoid being lured by arguments for investments which are peripheral to defense needs.

Arms exports have traditionally been used both as political "levers" as well as a way to spread development costs for domestic arms industries—every industrialized nation and many developing nations benefit from the arms trade in this manner. In the future we should expect commercial exports with defense applications to be promoted for both economic and national security reasons. Arms production has also been important to regional tax bases and political constituencies, primarily by offering a significant source of employment—as today evidenced by the reduction of U.S. military expenditures. It is not unreasonable to expect future national security arguments to be made in support of selected commercial activities—as already occurred in the debate over "critical technologies."

The reactive approach by the United States, reflected in the growing demands for trade protection by domestic industry and labor, represents "neo-mercantilist" urgings problematic for national security policies that must be founded in a world in which defense and commercial pursuits are closely aligned. This is particularly critical since the historical success of protectionist policies has been less than admirable. That is, while nations such as Japan have found merit in "infant industry" approaches to developing indigenous commercial capabilities, even they recognize that domestic industries must face "world-class" competition in order to succeed in the global marketplace. Without such direct challenges to the organization and conduct of business, firms tend to underachieve both domestically and internationally. Since defense production will come to rely much more significantly on commercial technologies and industrial capabilities in the future, the failure of U.S. industry to remain world-class will have a similar affect on U.S. military capabilities.

CONCLUSION: **In choosing dual-use investments, public policymakers must carefully consider the structure of the firms, industries, and markets which their programs are intended to influence. Such advice is not new. In the case of CMI, however, special attention must be given to the placement of and signals sent through government technology investments.**

In Part 2 of this paper we survey various techniques for choosing among technology investments and conclude that there is no "single best" approach to constructing a dual-use technology investment portfolio for the purposes of promoting CMI. Even retrospective assessments of prior technology investments are not always illuminating because of the myriad non-technological factors that may influence outcomes. We are thus led to rely on lessons from past investments to structure programs according to *a priori* beliefs in principles that will regulate their behavior and determine their performance—we invest according to *parables*.

Our discussions in Part 2 also illuminate difficulties which may be encountered in managing a large portfolio of technology investments. This is because the same issues in comparing the attractiveness of investment projects are raised when we attempt to measure their progress and ultimate impacts. As a result, the managers of an investment portfolio with a large number of projects are forced to abstract from specific characteristics and to rely on generalizations about their ultimate goals and utility. In this sense we are effectively managing technology as if it were an *icon*, where each project is accorded a simpler representation, itself a detail in a larger scheme.

Such "investment by parable and management by icon" suggests that success in promoting CMI with dual-use technology investments depends on the manner in which the government structures the selection of investments. That is, investments that fail to include the right mix of technical and management talent, commercial market astuteness, and understanding of military goals and needs begin with a disadvantage that is difficult if not impossible to overcome.

RECOMMENDATION: **There is a difference between dual-use technology investments and investments that will ultimately lead to commercial-military integration. Any successful long-term CMI strategy must seek to differentiate between what is potentially dual-use from a technological standpoint, and what is both commercially viable and militarily useful from both a technological and private marketplace standpoint. The following nine criteria are recommended as guidelines for choosing dual-use technology investments.**

1. General Defense Relevance

Dual-use technology investments must have a clear connection to future needs and requirements of the Department of Defense. *General defense relevance* pertains to the requirement that all CMI projects must further the cause of national security, either directly for military purposes, or indirectly through industrial base improvements which may be demonstrated as integral to providing for the national defense.

2. Attention to DoD Cost Drivers

Dual-use technology investments should target investments that promise to leverage significant cost savings for DoD. This *cost-reduction, rate-of-return criterion* is a corollary to so-called private rate of return. It focuses investments on the need to produce significant cost savings for national defense and emphasizes not only dual-use and co-production activities, but also personnel and training cost reductions.

3. Commercial Market Drivers

A *commercial market driver* exists when a commercial demand for a product or process coincides closely with a defense need. Dual-use technology investments should demonstrate strong linkages to future commercial markets, both in terms of the potential size of these markets and the nationality of firms likely to be major players in the markets. (There should be strong economic justification.)

4. Significant Technology Leveraging

To achieve desired defense-relevant goals, DoD should seek to *leverage the impact* of its dual-use technology investments by targeting areas in which there is clear under-investment by either the private sector, the public sector, or both. Expending DoD funds in areas where there are already large technology investments will have little leverage or pay-off.

5. Critical Path Roadblocks

Dual-use investments should target specific technical challenges that are unlikely to be addressed by the private sector alone. Such challenges constitute a *critical path roadblock* because promising future technology developments are curtailed by the high cost of overcoming one or more technical challenges. In some cases such challenges will need to be targeted based on defense needs alone.

6. Full Spectrum Industry Participation

Maximum impact from dual-use technology investments is most likely to vary directly with the number of participants in a development project. By *full spectrum* we mean the need to involve all parties with an interest in a project in a partnership or research alliance. This is important for two reasons: it is necessary to make sure that the industry leaders are involved to improve the chances for success; it maintains "safe" distance from commercialization/productization.

7. Portfolio and Cost Share/Capital Availability

A *portfolio* of dual-use investment projects with varying degrees of riskiness should be developed, and goverment support differentiated according to risk. There is a need to balance private rate of return with diversification of risk in a portfolio. Where risk is low, private sector investors should carry the primary burden for funding a project with commercial potential and military utility. Where risks are high and capital availability is an issue, there is a need to determine whether these circumstances derive from appropriability concerns or lack of information about opportunities.

8. Process Technology Focus

Process technologies are key to industrial base integration and should be a focus of dual-use investments. The essence of an integrated commercial-military industrial base is the ability to co-produce commercial and military items. But because international competition is leading to global out-sourcing, maintainance of a world-class industrial base necessitates that domestically based, U.S. firms maintain a competitive edge both in product and in process technology.

9. Social Rate of Return and Pervasive Impact

Dual-use technology investments should seek to maximize social benefits, particularly as a result of external effects from projects. A measurable, beneficial, direct impact on U.S. firms and national security should result from ultimate maturity of the technology development to be pursued. Beneficial impacts on firms include the creation of jobs, improvement in productivity, and increased profitability. Beneficial impacts on national security include reductions in weapon system costs, technological "leap-frogging" of foreign competitors' capabilities, and demonstration of co-production of military and commercial products.

RECOMMENDATION: **In order for dual-use technology investments to be successful, there is a need to improve DoD's ability to gauge the commercial attractiveness of such investments. To improve the prospects for successfully achieving CMI, DoD should assemble an in-house commercial assessment capability for use in determining the potential commercial viability of dual-use investments.**

As we move toward an integrated industrial base, there will be a growing need for commercial expertise within DoD to identify, recommend, and select investments appropriate to CMI. Beyond the Cold War technology-based approach to investment for the military, there is a need to address private and social rate of return characteristics as well. Unfortunately, such commercial financial and economic expertise is not yet available within DoD.

Immediately, DoD should seek to assemble a team of experts to assess and advise on the commercial viability and broader social impacts from proposed dual-use investments. To avoid conflict of interest issues, such a team could be drawn from retired executives in the commercial world, Federally Funded Research and Development Centers, and panels of the National Research Council.

Experts in finance should be recruited before investments are made to help examine the types of firms likely to be attracted by dual-use opportunities. These same experts could also assist with the oversight of investments through periodic progress reviews.

Experts in economics, and more specifically industrial organization, could be used to examine the likely market consequences of dual-use investments prior to committing to a project. In addition, they could look for externalities, spillovers, and linkages from these investments that would offer prospects of high social rates of return. Throughout project execution they would continue to monitor markets both domestically and internationally.

RECOMMENDATION: **Consideration of the role of the global marketplace and efforts to address it will become central to the success of CMI. It cannot be overemphasized that world-class commercial and dual-use industrial capabilities are the only means to an affordable military based on an integrated industrial base. Cross-border alliances, including consortia and partnerships, appear to be central to facilitating access to foreign technologies and capabilities that may reduce the cost of pursuing military applications. Such alliances take considerable time to coalesce, however, and DoD must begin to send "signals" to potential private sector investors with sufficient lead time for their formation. With greater reliance on the private sector, there is a need to promote commercial-military business alliances that seek to incorporate foreign technical and management innovations to speed the maturation of CMI investments and foster globally competitive U.S. commercial firms.**

In Chapter IV great emphasis is placed on developing a global strategic perspective necessary to cope with CMI. This perspective is essential for keeping U.S. security world-class since the underlying dual-use industrial base must also be world-class. In essence, DoD must avoid committing to projects that do not have the potential to help participants excel in the global marketplace.

To realize such a strategy, dual-use investments must combine the best of both the commercial and defense "worlds." For instance, European and U.S. experience suggests that strategic alliances and appropriately structured prime/supplier relationships are important because of the complex nature of modern weapon systems. Alliances and consortia are also rapidly becoming the norm for commercial endeavors, and have demonstrated significant advantages in promoting enterprise agility, reducing costs, and delivering quality.

INTRODUCTION

Technological progress affects our daily lives through almost everything we read, hear, see, discuss, or experience. From children's cartoons to kitchen appliances, hand guns to stealth fighters, technology defines our quality of life and the historical stages of our existence.

We are taught the American West was "won" because a technological revolution in rail transportation supported expanded continental migration and commerce; we describe the Cold War in terms of the nuclear and advanced conventional weapons with which the United States and U.S.S.R. armed themselves; and we see the future of human interaction and daily life in terms of transformations resulting from faster computers, high capacity telecommunications, and vast information networks. In short, we view technology as the "fix," or panacea, for every societal problem, including unemployment,[1] industrial uncompetitiveness, health care inefficiencies, and unaffordable defense.

Investments in new technologies alone cannot cure society's ills, however. To take full advantage of technology investments, other factors must also be in place: a better educated work force that can assimilate new ways of producing; reformed and increasingly flexible management practices to adapt business practices to rapid changes; greater harmony between industry needs and government policies; and a redefinition of work and success within the evolving techno-economic landscape.[2]

Even in an environment conducive to technological progress, it is difficult to decide what types of investments to undertake. Immense difficulties are encountered when one attempts to choose projects not only from a technical perspective, but also from the perspectives of private and public sector decision making. The relative "goodness" of one investment over another is difficult to assess a priori, and the outcome of an investment can only be projected with uncertainty. While we accept that technological

1 Technological change is generally seen as labor-displacing in the short term, although its contribution to economic growth in the long term has generally led to the creation of new jobs.

2 This is particularly true given that robotics and automation are reducing the need for human intervention and leading to a host of new occupational categories.

progress offers potentially sizable economic benefits, we have yet to fully understand the causal links involved in deriving such benefits.

We must consider, then, how we may use our limited understanding of the relationship between technological change and economics to improve the way in which such investments are targeted. Commercial firms have already made such considerations part of their decision making, but the Federal Government is only beginning to recognize the need to force a confluence of agency mission-oriented goals with broader social and economic goals.

This paper reviews the current "state-of-understanding" for making private and government technology investment decisions and examines how this understanding may be applied in selecting dual-use technologies to further the goal of commercial-military integration (CMI). The discussion is divided into two parts.

Part 1 provides an economic framework for understanding the obstacles and issues involved in pursuing an integrated industrial base by addressing the following:

- What is CMI, and what is the role of dual-use technology in promoting an integrated industrial base?
- Are there likely to be repercussions in commercial markets from attempts to jointly satisfy commercial and military demands?
- Are there measures which may be employed to gauge the extent to which integration efforts are succeeding or paying off?
- How does CMI "play" in the global economy, and what are its implications for national security?

Part 2 of the paper reviews the three dimensions of assembling a public sector technology investment portfolio—technical, private rate of return, and social rate of return selection methodologies. It addresses the following:

- Is it possible to develop completely objective technology investment selection criteria?
- To what extent are financial calculations useful in sifting through investment choices?
- What is meant by social rate of return, and why is this an important part of making investment choices for public policy makers?

A summary is provided at the end of each chapter. Conclusions and recommendations are offered in Chapter VII.

PART 1

THE ECONOMIC FOUNDATIONS OF COMMERCIAL-MILITARY INTEGRATION AND DUAL-USE TECHNOLOGY INVESTMENTS

INTRODUCTION TO PART 1

While the notion of relying on the commercial industrial base for the needs of the military is not new, it is nevertheless resurgent. During the Cold War, increasingly specialized defense technologies were employed to offset the numerical inferiority of U.S. and Western Alliance forces compared with those of the Warsaw Pact, China, and other nations. This led to the emergence of two separate and distinct industrial bases in the United States, one catering to the needs of the military, the other fully engaged in domestic and global private sector commercial market activities.

Today, with the Cold War over, defense budgets falling, commercial technology advancing, and commercial innovation accelerating, the notion of relying on the commercial sector for the military's technology needs—once considered a criticism of DoD practices—is being embraced anew. This sea change has spawned new discussions which seek to operationalize broad, and at times "fuzzy," principles concerning commercial-military integration (CMI). In fact, these discussions actually derive from a mature debate about the gains that would accrue to the nation by recombining the commercial and military industrial bases, most recently joined by influential reports from DoD's Defense Science Board, the Center for Strategic and International Studies, the Carnegie Commission, and the Office of Technology Assessment.[3]

Still missing from the policy discourse, however, is a rigorous theory of CMI—a framework for explaining why it occurs where it does; why it doesn't occur more (or less) frequently; what forms it is likely to take; how to encourage or cultivate it; or even how to measure the degree to which it takes place. Interest in developing such a framework, either on a theoretical or practical basis, has been dampened by administrative and

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[3] Department of Defense, Defense Science Board, *Engineering in the Manufacturing Process*, March 1993. Department of Defense, Defense Science Board, *Use of Commercial Components in Military Equipment*, Mimeo, July 1989. Department of Defense, Defense Conversion Commission, *Adjusting to the Drawdown*, December 31, 1992. Center For Strategic and International Studies, *Critical Issues In Defense Conversion* (mimeo draft) 1994. Carnegie Commission on Science, Technology, and Government, *Technology and Economic Performance*, September 1991. Office of Technology Assessment, *Redesigning Defense: Planning the Transition to the Future U.S. Defense Industrial Base*, July 1991. OTA, *After the Cold War: Living With Lower Defense Spending*, February 1992. OTA, *Building Future Security: Strategies for Restructuring the Defense Technology and Industrial Base*, June 1992. See also: S. J. Deitchman, *Beyond the Thaw: A New National Strategy*, 1991.

procedural barriers erected over time by DoD and by legislation from Congress. Indeed, until recently, the likelihood of an integrated industrial base has been slight. To fill the void, this part of the paper constructs a framework for understanding CMI: where it may be appropriate, what its market impact may be, how it might be measured, and what it may imply for national security in an increasingly integrated global economy.

I. COMMERCIAL-MILITARY INTEGRATION: A NEW APPROACH TO NATIONAL SECURITY

In general, we believe most of the technologies the Defense Department depends upon—electronics, semiconductors and computer software, to mention a few—have equivalents in the commercial industry. Therefore we do not believe we have to maintain a defense-unique capability in those areas.

—Dr. William Perry, Secretary of Defense[1]

Events since the demolition of the Berlin Wall in 1989 have dramatically changed the face of international security. With challenges from the USSR rapidly fading and no comparable threats apparent in the near future, the United States is shifting its attention and resources to address domestic needs. The new focus is on economic security—providing for high quality (well paying) employment and increased social welfare for U.S. citizens within the context of the competitive, global marketplace.

While the Cold War may be over, recent developments in the Middle and Far East, Africa, Europe, and the Caribbean suggest that military security will remain an important concern for the foreseeable future. To deal with anticipated regional contingencies, U.S. forces need not be as vast as they were during the past 45 years; however, they will continue to face formidable challenges. Our choices are either to equip the military from a shrinking, dedicated defense industrial base and face certain degradation in quality and capabilities, or to adapt military requirements and procurement strategies so that they rely upon commercial industrial capabilities.

The second approach, increasing reliance on commercial sources, involves integrating the defense and commercial industrial bases which evolved as separate and distinct during the Cold War. This is termed "commercial-military integration" (CMI). The essence of CMI is that sufficient commonalty between commercial and defense needs can be "designed into" military systems and weapons so that commercial capabilities can fulfill the vast majority of defense requirements. In research and development this goal is pursued through so-called dual-use technologies—technologies

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1 Anthony L. Velocci, Jr. "Perry Forges New Shape for Industry," *Aviation Week and Space Technology*, November 15, 1993, p. 56 (hereafter cited as "New Shape for Industry").

that are both commercially viable in the competitive marketplace and militarily useful either directly or with limited modification.

Within a changing environment shaped by rapid innovation, classifying the "dual-usefulness" of new technologies and their applications involves exploring dynamic interrelationships, beginning with scientific discovery and extending through the manufacture and life-cycle support of finished "products." In some cases, military requirements cannot be met by commercial industry or they may "contradict" commercial needs and practices. For instance, if the warning time prior to a conflict is short, the quantity of newly produced high technology weapon systems that will be available will not be significant under a regime of peacetime production. This means that more traditional approaches to stockpiling and maintaining materiel reserves will continue to be central to national security.

Instances where commercial capabilities and military requirements may be mutually satisfied, however, offer significant opportunities for DoD to leverage private sector investments to speed technology development and improve affordability through market economies. To embark on a dual-use technology investment program that will realize CMI, DoD needs to change its approach to procurement and technology investment, incorporating greater flexibility. Such changes are necessary to accommodate the considerable variance among the possibilities that CMI represents. For instance, at one extreme, complete CMI could be characterized as commercial and military products employing identical production processes and being sold at comparable, competitively set market prices. This would be the same as purchasing all military requirements "off-the-shelf," an unlikely outcome even in the long run. At the other extreme, absence of CMI would be much like "business as usual" today—military products requiring practices and production techniques that have little in common with those of the commercial world.

In fact, the sometimes significant differences between DoD and commercial goals mean that we should not expect to achieve complete CMI for all military products and that it will be the intermediate cases that will yield the greatest benefits to DoD from a cost and performance standpoint. Large military platforms, such as armored vehicles, fighter aircraft, and warships, will continue to be produced within a traditional Cold War contractor-type or perhaps an arsenal environment.[2] With CMI, however, their

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[2] Ibid.

components, such as radar, engines, communications gear, and so forth, would be produced to address a range of different requirements from the military-unique to commercial-off-the-shelf. In many cases, it would be possible to "share" commercial production facilities, an arrangement called "co-production."

A. COMMERCIAL-MILITARY INTEGRATION AND DUAL-USE TECHNOLOGIES—IMPORTANT DISTINCTIONS

It is important to clearly distinguish between dual-use and CMI. *When we speak of "dual-use," we are referring to a product or process that has both military and commercial applications. In the case of dual-use technologies, this extends to knowledge*[3] *that is applicable in both sectors.* The concept of dual-use therefore relates to the characteristics of a product, process, or know-how without regard to the desirability of its application in either sector. Hence, an item might be dual-use and employed militarily but not commercially because of cost, performance, regulations, or other considerations.

CMI, on the other hand, is a process that seeks to exploit the "dual-usefulness" of products or processes to arrive at more efficient and cost effective solutions jointly for the commercial and military sectors. *Commercial-military integration is achieved when the production of commercially viable and militarily useful products is conducted jointly using common production inputs, and outputs are sold at prices comparable to those set by commercial markets.* Note that this definition involves two dimensions, an engineering one ensuring the commonalty of resources and production techniques, and an economic one ensuring the comparability of costs and prices. The former represents the traditional Cold War military considerations regarding performance; the latter, the post-Cold War affordability concerns that underlie CMI as pursued through current DoD policies.

Not everyone accepts the possibility of integrating military and commercial needs within a unified production and distribution environment. Some say that the differences between the two sectors are driven by product design requirements that press the limits of engineering feasibility. Some argue that labor costs in defense markets tend to be greater than in their commercial counterparts because of stringent production and administrative requirements, or that DoD production runs are too small to yield commercially viable

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3 We include know-how as part of big "K" knowledge.

economies of scale. And some point out that the composition of the work force in defense sectors is relatively labor-intensive, composed of precision-oriented production workers, technicians, engineers, and large administrative support staffs associated with engineering-intensive work.

For others, CMI conjures such fanciful goals as building M-1 tanks and Chevrolets on the same assembly line, or eliminating the distinction between military and commercial goods and services altogether. In the latter case, all military purchases would be from off-the-shelf commercial sources, and there would be no need to maintain any sort of military-unique production at the component level. Commercial sources and technologies would form the basis for national security.

The reality of CMI, however, is that it can be realized through a broad spectrum of dual-use possibilities between the purely military and purely commercial wherein some product and process technologies are conducive to jointly meeting the needs of the two sectors and some are not. Opportunities along this spectrum include the use of flexible manufacturing systems to co-produce military and commercial variants of the same item in the same facility, insertion of commercial items into military platforms, and investment in new technologies that are anticipated to have dual-use. Important bastions of commercial- and military-unique production will continue to exist, however, and not all intermediate dual-use opportunities will be exercised as a part of CMI.

Figure I-1 depicts one way of thinking about changes that lead to increased military reliance on dual-use technologies. Along the vertical axis we have a simple, four-stage model of technology development and deployment; along the horizontal axis is a continuum from purely military to purely commercial technologies. Inside the figure are three areas, one each for military-unique, commercial-unique, and dual-use product and process technologies. Increased use of dual-use technological and industrial capabilities by the military is represented by a migration of the diagonal lines in the figure in the northwesterly and northeasterly directions, resulting in a shrinkage of military- and commercial-unique technology applications.

For instance, the production of militarily useful components of weapons and systems on commercial lines—exemplified by the use of commercial electronics for the Army's Common Hardware and Software (CHS) program, which competes and qualifies commercial vendors to supply "ruggedized" versions of non-Mil-spec equipment—might be thought of as pushing the "boundaries" between commercial and dual-use in Figure I-1 to the northeast. Efforts which are under way to review and harmonize Mil-specs with commercial requirements and capabilities (which in some cases are more rigorous and modern than their military counterparts) could be seen as pushing the boundaries between military and dual-use to the northwest.

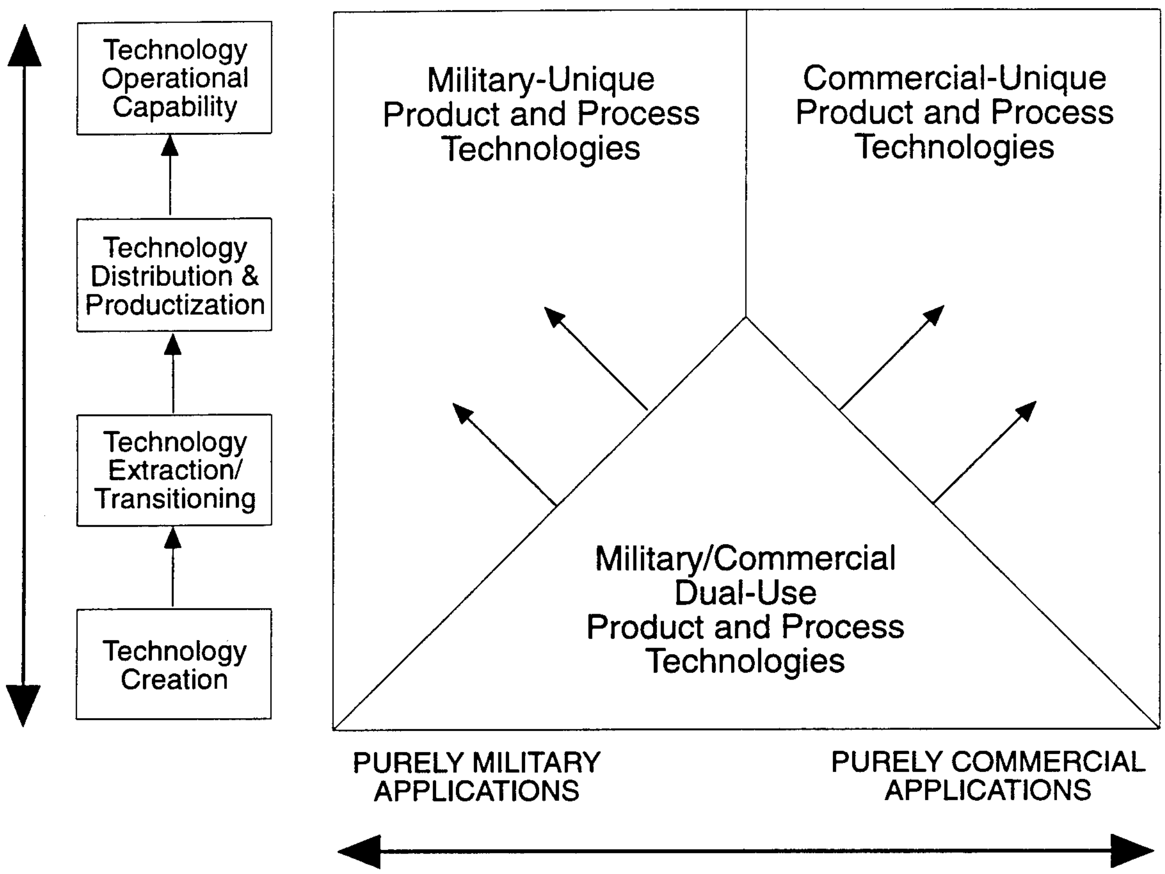

Figure I-1. Dual-Use Technology Space

There are practical limits to the degree that integration will occur, however, because some military requirements are incompatible with commercial needs.[4] Within the domain of military-unique technology developments are such examples as stealth aircraft, cruise missiles, and radiation-hardened microelectronics. Reducing radar cross-sections with stealth technologies simply does not fit with commercial air transportation—"being seen" by radar is an important air traffic safety consideration. The technologies used in constructing and targeting cruise missiles may have some relationship to the development of commercial aircraft, but military uses of autonomous

4 Velocci, "New Shape for Industry," p. 56.

vehicles and of target recognition are today at best "cousins" to their commercial counterparts. The need for radiation-hardened microelectronics which can survive extreme levels of electromagnetic interference would appear to be beyond the vast majority of nonmilitary applications.

Of the military technologies that have been purposefully spun off to the commercial sector, prominent are the development of microelectronics and super computers, commercial jet aircraft and aircraft engines, the global positioning system (GPS), and composite materials.[5] In each of these examples military requirements were close enough to their commercial counterparts to find quick acceptance in the commercial sector. In the case of microelectronics, the Defense Advanced Research Projects Agency pursued activities that led to the development of the integrated circuit for use in ballistic missile guidance systems; in the case of super computers, it pursued high-speed numerical calculation capabilities to assist in the design of other advanced systems and to facilitate cryptography. The Boeing 707 and 747 aircraft are derivatives of defense-funded research into new aircraft designs; global positioning satellites had their origin in the military's need for precise targeting information;[6] and composite materials arose from the quest for lighter, stronger airframes and armor systems but are now being used in commercial products.

We must recognize, however, that this trend of using military technologies in commercial applications is changing. In the future the private sector is expected to channel much larger investments into commercial technologies that will have increasing relevance in military applications.[7] In the United States this is already true for advanced flexible manufacturing and computer-aided design, areas in which commercial industry holds a lead over the military. In Japan a much smaller defense R&D budget has led to a direct adaptation of commercial technologies in lieu of custom-designed military equipment.[8] Some developing nations are also pursuing this path in an effort to attain indigenous defense industrial capabilities. Many commercial technologies currently available are comparable to the most advanced military technologies of only a decade ago, leading to medium-tech defense programs for indigenously designed armor, aircraft,

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5 See Alic, et al., *Beyond Spinoff*, 1992, for a comprehensive history and treatment of dual-use technologies.

6 GPS is still a military system, but it is being offered for civilian use.

7 Office of Technology Assessment, *Redesigning Defense*, 1991, p. 3.

8 Office of Technology Assessment, *Global Arms Trade*, 1991, pp. 42–43.

and naval vessels. The Chilean Navy, for instance, will employ standard IBM computer architectures in domestically designed command and control systems aboard selected vessels in its fleet;[9] the Dutch Navy will use commercial VAX computers for similar command and control uses.[10]

While such dual applications are efficacious, they introduce significant problems relative to both domestic weapons producibility and the international proliferation of such capabilities. German and Japanese machine tools, Japanese robotics, and other foreign equipment and processes are today required to deliver U.S. weapon systems. In a variety of cases where foreign manufacturing techniques are superior to those found in the United States, the U.S. military will need additional foreign know-how if it is to improve quality and reduce costs in the future. In fact, the trend in the U.S. today is toward increased use of a mixture of foreign and domestic manufacturing technologies to support the defense industrial base.[11]

Therefore, while commercial-military integration may be seen as the restructuring of the U.S. industrial base so that commercial sources may be used to meet military needs, it is also bringing the military closer to commercial practices which continually seek to align themselves with global competitive realities. Even if the United States uses only domestic components and materials, it will not be assured freedom from foreign process technologies. Attaining and maintaining a world-class military in the future will increasingly become a global endeavor leading to a concomitant spread of militarily useful technologies and know-how. This will be equally true for the unique requirements of the military that will not easily conform to those of the private sector, such as for large platforms (e.g., submarines and stealth aircraft).

B. CAN COMMERCIAL-MILITARY INTEGRATION MEET THE WARFIGHTING NEEDS OF THE MILITARY?

Because ultimate DoD and commercial goals differ, even in the long run we should not expect to achieve complete CMI for all military products. There are no commercial uses for the most advanced weapons systems "platforms," such as armored

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9 *Jane's Defense Weekly*, 21 March 1992, p. 467.

10 Joris Janssenhok, *Jane's Defense Weekly*, 14 March 1992, p. 443. Even so, the capabilities of computer hardware are and will remain a function of software, and the majority of this which is useful to the military is likely to remain defense-specific.

11 See, for instance: National Academy Press, *Finding Common Ground: U.S. Export Controls in a Changed Global Environment*, 1991, pp. 40-42.

vehicles, fighter aircraft, or warships. Some degree of CMI may be achieved, however, through the use of commercial components, or military components co-produced where inputs are shared with commercial analogs.

While DOD dual-use investments are intended to have beneficial economic effects, their national security emphasis focuses them much more narrowly on the issue of providing a future, integrated industrial base that is capable of maintaining a world-class U.S. military. A key question is how well can such investments and facilities support weapon system production, or how much can be delivered and when. Any honest investigation of this question must acknowledge that it is no simple task to determine the exact time or industrial base resources required to produce modern weapon systems, high-tech or not. For CMI the answer is particularly elusive because the resources and technologies that will be available from an integrated industrial base are as yet unknown and impossible to project. Furthermore, even with CMI there will remain a need to stockpile weapons and materiel—a commercial-type just-in-time system does not accommodate surge military requirements.

For instance, the Desert Shield/Storm experience teaches that in the case of short conflict warning times it is unlikely that demands for weapons systems will be met by peacetime production capabilities, CMI or not. The U.S. military will still need to maintain large stockpiles of moderate and long lead time weapon systems in quantities anticipated to be sufficient to meet "worst case" conflict scenarios. The Desert Storm experience provides some notion of the size of such stockpiles of weapons. As reported in the *Conduct of the War Report*, munitions usage during Operation Desert Storm (ODS) far exceeded the authors' estimates of peacetime ability of the defense industrial base to respond with new deliveries (see Table I-1).

Table I-1. Desert Storm Munitions Usage

Item	Desert Storm Usage	Max. Production/ Month[a]
Multiple Launch Rocket System	9,660	6,000
Maverick (AGM-65)	5,100	125
Air Launched Cruise Missiles	35	10
Sea Launched Cruise Missiles	288	54

Source: Department of Defense, *Conduct of the Persian Gulf War*, April 1992, pp. 753–787. Usage refers to total use during Desert Storm.

[a] Monthly rate based upon observed peak peacetime annual procurement rates taken from the U.S. Missile Data Book, 1994, Data Search Associates, pp. 2-1 to 2-40.

Data in Table I-2, also taken from the *Conduct of the War Report*, offers another view of the "ramp-up" time for a variety of items—none of which may be considered high-tech. The Report states that for more complex weapon systems, such as the AH-64 Apache attack helicopter, at least 19 months would be required to move from a production rate of six to eight units per month.[12] Furthermore, the *Report* cites no instance in which the *production* of high technology weapon systems was "surged," perhaps an indication of the immense difficulty of doing so. (Depot maintenance and overhaul of systems, however, were surged.)[13]

Table I-2. Selected Surge Production Capacities

Item	Pre-ODS Production per month (000)	Maximum Capacity per month (000)	Time to Reach Maximum Capacity (months)
Desert Battle Dress Uniform Coat	0	446	9
Desert Boot	0	157	8
Chemical Protective Suit	33	200	9
Nerve Agent Injectors	60	717	8
Sandbags	84	326	6
Tray-Pack Rations	1.3*	4.7*	9

Source: DoD, *Conduct of the Persian Gulf War*, p. 434.
*Millions of meals

We should therefore look askance at stories reporting the apparent "miraculous" design and delivery of new weapon systems in short periods of time prior to or during a war. In most cases anecdotes such as these refer to the modification of existing weapon systems, the adaptation of off-the-shelf commercial capabilities for military use, and unique heroics which must be regarded as exception rather than rule. Two of the most prominent examples during Desert Shield and Desert Storm were the acceleration of deliveries for the Pak II Patriot air defense missile and the development of the GBU 28 "bunker busting" PGM. Both cases are examples of so-called "work arounds."

12 Department of Defense, *Conduct of the Persian Gulf War*, p. 433.

13 Ibid., p. 432–435.

In the case of the Patriot, Raytheon delivered over 600 Pac-2 missiles within the 6-month period prior to Desert Storm. These variants of the weapon were essential to provide anti-ballistic missile protection from Iraqi SCUDs for ground troops and installations. Raytheon's effort was commendable: bureaucratic production restrictions were relaxed; not all of the missiles delivered were "newly" produced but were weapons in the existing inventory that were modified with new software and warheads; while others were produced by a German company, MBB.[14]

For a true example of "necessity as the mother of invention," we cite the GBU-28. It resulted from the recognition that existing munitions were incapable of defeating the protection of some Iraqi command bunkers. To achieve a munition with sufficient mass to afford necessary penetration capabilities, 8-inch artillery gun barrels were paired with laser-guided munitions "kits" and certified for use within a 27-day period.[15] Hence, a very specific capability gap was filled in short order.

More generally, work done for the U.S. Department of Defense to assess industrial mobilization capabilities confirms the inflexibility of weapon systems production environments. Table I-3 estimates the time required to produce a variety of modern, high technology weapon systems such as precision guided munitions ("smart bombs"), fighter aircraft, and naval vessels. It summarizes for groups of "similar" weapon systems manufactured under peacetime production conditions, the time between when an order for an additional increment of production for a weapon system is placed with a prime contractor, and when that additional unit is completed and available. It suggests that if the warning time prior to a conflict is short, the quantity of newly produced high technology weapons systems that will be available will not be significant under a regime of peacetime production.

C. HARMONIZING COMMERCIAL AND MILITARY REQUIREMENTS

Although the need for long lead times in defense production is likely to continue, shorter weapon system design/development/production cycle times may be possible, and it may be feasible to insert dual-use technologies into platforms and weapon systems. Advances in the design, manufacture, and servicing of both commercial and defense

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14 United States Army, *Certain Victory: United States Army in the Gulf War*, 1993, pp. 71–73.

15 DoD, *Conduct of the Persian Gulf War*, pp. 165–166.

Table I-3. Industrial Lead Time Estimates

General Category	Lead Time[a] (Months)
Missiles and Torpedoes	10 to 48
Rotary Aircraft	20 to 44
Fixed-Wing Aircraft	36 to 60
Ships (Ex. Aircraft Carriers and Submarines)	48 to 60
Aircraft Carriers and Submarines	72 to 84

Source: Richard H. White, et al., Documentation for the Forces Mobilization Model (FORCEMOB): Theoretical Foundations, IDA Paper P-2716, Volume I, July 1992.

a These lead times represent the peacetime period required to produce an additional unit of output within each of the categories, assuming that "warm" production facilities exist (e.g., an additional helicopter takes 20 to 44 months to deliver from the time it is ordered). Of course these lead times could be reduced somewhat during wartime mobilization, but it is unlikely that such reductions would offer any real advantages in a war of short duration with little lead time.

products in the past several decades foreshadow potentially significant changes for production capabilities. Today, for instance, the so-called "envelope of flexibility" that defines the types of products that may be co-produced on a single assembly line is quite rigid or constrained. In the future, increased flexibility may allow the simultaneous production of defense and commercial goods on the same line. Indeed, advances in both weapon system and manufacturing simulation capabilities portend greater concurrence in product and process design and engineering, leading to significant reductions in the time required to bring new ideas out of research into existence. Even today, DoD could seize upon existing possibilities for "decoupling" production lot size and unit cost to allow sequential production of commercial and military variants of products.

The need to plan well in advance for dual-usefulness also has particularly important implications for weapon system affordability since design changes after the R&D stage that are not met by concomitant capabilities in production or final assembly are extremely costly. In particular, the consideration of new commercial technologies for incorporation into military systems, and the development and application of commercial technologies so that they have dual-usefulness designed in, will require that such principles as concurrent engineering, flexible and agile manufacturing, and the virtual organization of design, development, and production be embraced by the military.[16]

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16 See: Iacocca Institute, Lehigh University, *21st Century Manufacturing Enterprise Strategy: An Industry-Led View*, 2 Volumes. March 1992. Robert I. Winner, James P. Pennell, Harold E. Bertrand,

Furthermore, if current trends continue, there is no guarantee that geographic proximity will be the norm for commercial operations. Advanced engineering design tools capable of supporting "virtual" design activities independent of location are a reality in many private sector endeavors (and some military ones as well). Such capabilities must be leveraged to promote the coordination necessary to develop dual-use systems. This will also open up greater opportunities for "joint" learning between government and industry, as in the case of Boeing's new "paperless" design of the 777 passenger aircraft, where earlier company experience with design automation on the B-2 bomber project has been advanced to a new state of the art.[17]

The real issue for the development of dual-use technologies in support of co-production will therefore be highly dependent upon improved information "flow" and coordination. To achieve co-production, military requirements must be fed into commercial decision-making processes at the earliest stage possible. Three principles must be followed for this to occur:

1) Sufficient lead-time must be afforded commercial firms so they will be able to assess the costs and earnings potential of co-production activities.
2) Co-production cannot lead to modification of commercial products in such a way as to diminish their market acceptance.
3) Military requirements must be flexible enough to allow their modification to take advantage of emerging, fast-changing commercial approaches to product/process definition, design, development, production, and distribution.

All of this suggests that in order for the co-production potential of CMI to be achieved, commercial and DoD interests must "intersect" earlier—at the advanced

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and Marko M. G. Slusarczuk, *The Role of Concurrent Engineering in Weapons System Acquisition*, IDA Report R-338, December 1988. Defense Science Board, *Engineering in the Manufacturing Process*, March 1993. Peter F. Drucker, "The Emerging Theory of Manufacturing," *Harvard Business Review*, May-June 1990. Rafael Aguayo, *Dr. Deming*, 1990. W. Edwards Deming, *Out of the Crisis*, 1986. Cohen and Zysman, *Manufacturing Matters*, 1987. Bowen, et al., The Perpetual Enterprise Machine, 1994. Davidow and Malone, *The Virtual Corporation: Structuring and Revitalizing the Corporation for the 21st Century*, 1992. Hammer and Champy, *Reengineering the Corporation: A Manifesto for Business Revolution*, 1993. Peter M. Senge, *The Fifth Discipline: The Art and Practice of the Learning Organization*, 1990.

17 Gary Stix, "Plane Geometry: Boeing Uses CAD to Design 130,000 Parts for Its New 777," *Scientific American* (March 1991, Volume 264), p. 110. Dori Jones Yang, "Boeing Knocks Down the Wall Between the Dreamers and the Doers: The 777's Design and Manufacturing Types Are Sweating the Details Together Before Production Starts," *Business Week* (28 October 1991) p. 120. Also, see most recently a collection of articles on the "rollout" of the 777 in *Aviation Week and Space Technology*, April 11, 1994.

engineering and applied research stages of product/process development—rather than at the late product development and direct commercial purchase stages, as they do now. (See Figure I-2.)

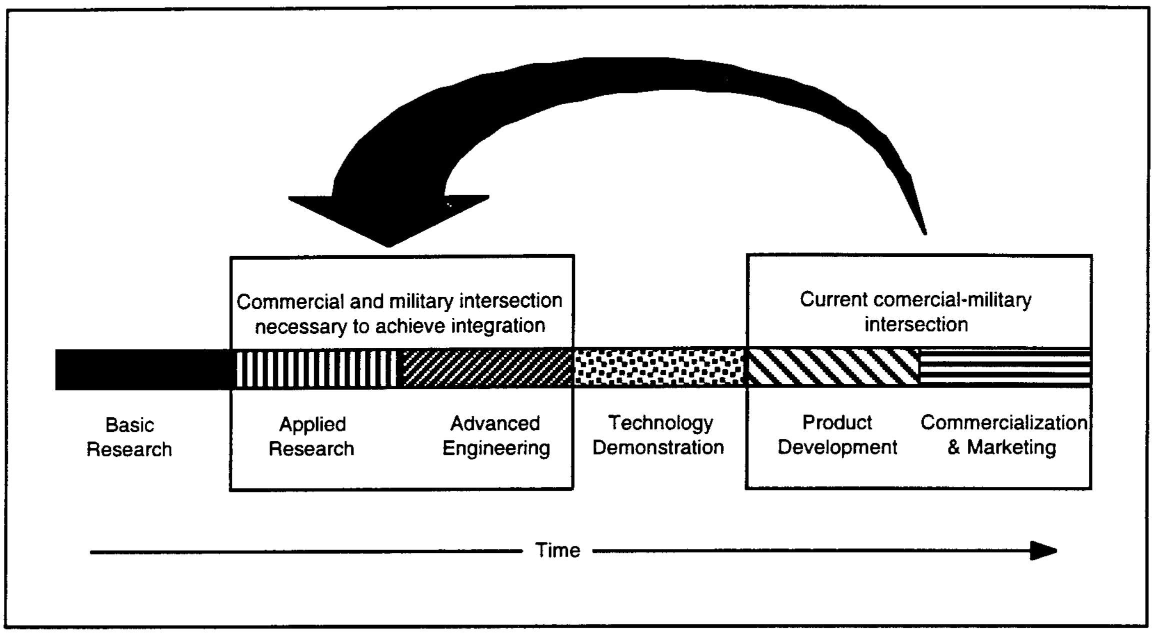

Figure I-2. Shift in Emphasis to Achieve Commercial-Military Integration

To achieve the strategic positioning necessary for future co-production activities we need to promote development of dual-use product and process technologies *today*. Since these products and processes must be acceptable and competitive commercially before they can become available at a low cost to the military, it is necessary to focus public expenditures where commercial leverage will be greatest in reducing defense outlays. In other words, commercial interest must be channeled into dual-use activities that have both a high probability of success *and* potential to significantly reduce costs for DoD procurement.

Co-production of weapons systems/components must therefore be based upon the availability of commercially viable, cost effective, timely process technologies. The determining factor for success will be the extent to which the DoD procurement system is able to accommodate commercial approaches to doing business. Success in this endeavor will come only when DoD procurement is managed according to commercial competitive exigencies:[18] design and production activities must become more efficient and cost-effective at the same rate for both sectors. This will require concurrence in the design, development, production, and deployment of both commercial and military product and process technologies.

D. CMI AND MILITARY NEEDS: OBSERVATIONS

Even if all of the potential offered by lean, flexible, and ultimately agile manufacturing practices are realized, expectations about the future must not be allowed to become unrealistic. Weapon production lead times are longer today than in the past because of the complexity of systems and platforms. Even with state-of-the-art production processes, production times are still likely to be lengthy when pushing the envelope of new technologies. Furthermore, while flexibility in production may become a reality for many items, the scale of many militarily unique production facilities—for weapon systems not amenable to civilian co-production—will limit the number that may be produced over any given period of time. Thus, no matter how rapidly workarounds and other quick reactions have been accomplished in the past, we cannot conclude that the United States should rely on potentially serendipitous forms of preparation for war.

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[18] See, in particular, Womack, Roos, and Jones, *Machine that Changed the World*, 1990, where the authors amply demonstrate the importance of operating within the correct "competitive paradigm." They contend that two different ways of managing production arose after the World War II. One, based on the pre-war philosophies of Ford and Sloane and dubbed "mass production," is characteristic of businesses in the United States and Europe. This is the traditional assembly line approach to enterprise management and the use of production technologies exemplified by the "big-three" U.S. auto makers prior to the late 1980s. The other, originating in Japan, is termed "lean" production and is exemplified by Japanese auto manufacturers.

Lean production encompasses changes in the management of productive enterprises that reduce costs, increase quality, and improve efficiency, such as just-in-time inventory control, flexible manufacturing, worker empowerment, reduction in waste and scrap, adoption of statistical process control techniques, decoupling of price and quantity in production. Many "programs" aimed at achieving such goals in the West are now being adopted, such as Total Quality Management (TQM), Total Quality Control (TQC), and concurrent engineering (CE). It is noteworthy that the Department of Defense has attempted to adopt, and in some instances has been a pioneer in applying, "lean" principles. Recently, the U.S. Air Force announced a study of its own, the "Lean Aircraft Initiative," to pursue lean production for military aircraft. Significant goals for U.S. security are to develop "quality products in a shorter time and at lower costs," and to acquire information on how to reform the acquisition system. *Aviation Week and Space Technology*, May 24, 1993, pp. 23-4.

Lean production practices will have to extend to all aspects of defense acquisition if the true potential for commercial-military integration is to be realized. The real issue is whether defense acquisition practices will ever be able to adjust quickly enough to changes in the private marketplace to harmonize military needs with commercial opportunities. To achieve such integration it will be crucial that the management philosophies of the Department of Defense reflect commercial realities. Otherwise, firms catering to the private sector will not be willing to participate in co-production activities because they will represent a "drag" on operations and profitability.

Rather, quick turnaround successes suggest that there is more flexibility in both the procurement and industrial mobilization processes than generally believed, and that this should be part of the vision of the integrated industrial base.

Assuming that the restrictive rules and regulations governing defense acquisition are surmounted—and this is a major assumption—it is clear that unique military requirements that cannot be met through commercial or dual-use channels will remain, even if we are completely "successful" in promoting CMI. The issue confronting DoD, therefore, is not how to achieve complete dependence upon commercial sources, but what represents a prudent mixture of industrial resources from a national security point of view.

Once we accept the premise that complete commercial dependence is out of the question, the next task is to clarify what constitutes prudent commercial reliance. This clarification, in turn, is bounded by what will ultimately be acceptable to commercial firms doing business with DoD. Clear and undisputed evidence has shown that the motivations for private and public sector investments in technology differ significantly.

The real issue, therefore, is not about technology itself, but the way in which we will seek to apply it to military needs in the future. If the ultimate goal is to rely more heavily on commercial industrial capabilities, DoD must be willing to accept all that this entails, including commercial design, development, accounting, personnel, and other practices. This is central to the success of CMI since commercial firms will not voluntarily participate in integration efforts if DoD requirements represent a drag on their operations.

Successful integration will also require an openness to altogether new approaches. For instance, it may become more efficient to design and construct weapon system platforms jointly with other nations, but to outfit them with weapons and systems unique to the U.S. military. One could imagine common vehicle designs with armament supplied by national firms. While unlikely for political reasons, such an approach would mirror the current commercial trend toward outsourcing and would allow U.S. defense dollars to be concentrated on unique, force-multiplying technologies to maintain a qualitative edge.

CMI is most likely to take hold where shrinking defense budgets force changes in attitudes and opportunities arise to allow DoD to adopt commercial practices: off-the-shelf commercial components and co-produced items; reliance on commercially viable process technologies; and, the adoption of commercial management philosophies.

We will know the limits to CMI through the willingness of private sector enterprises to engage in the process and offer items useful to both sectors. Where the anticipated profitability of designing and producing a military item along with a commercial item yields at least the same return on investment as producing the commercial item alone, both may be pursued; where the return on investment is reduced by the inclusion of military requirements, only the commercial item will be pursued.

E. SUMMARY

- It is important to clearly distinguish between dual-use and CMI. When we speak of "dual-use," we are referring to a product or process which has both military and commercial applications. In the case of dual-use technologies, this extends to knowledge that is applicable in both sectors.
- CMI must be viewed as having two distinct dimensions: an "engineering" one ensuring the commonalty of resources and production techniques; and, an "economic" one ensuring the comparability of costs and prices. As such, CMI may be said to occur only when the production of commercially viable and militarily useful products is conducted jointly using common production inputs, and outputs are sold at prices comparable to those set by commercial markets.
- Despite all of the purported benefits of CMI, there are practical limits to the degree that integration will occur. In some cases, military requirements are incompatible with commercial needs and practices.
- If the warning time prior to a conflict is short, the quantity of newly produced high technology weapon systems that will be available will not be significant under a regime of peacetime production. Consequently, more traditional approaches to stockpiling and maintaining materiel reserves will continue to be central to national security.
- Although many have posited significant potential for spinning off military technologies for commercial use, today most military technologies have few if any commercial analogs or applications. In fact, future investments in commercial technologies by the private sector are expected to be increasingly relevant for military applications; thus, spin-on is the more likely route for CMI.
- Because commercial enterprise is rapidly becoming globally integrated, entwining commercial and military technologies introduces new issues

regarding the domestic producibility of weapons systems and the international proliferation of advanced military capabilities.

- To achieve the co-production potential of CMI, commercial and DoD interests must "intersect" earlier—at the advanced engineering and applied research stages of product/process development—rather than at the late product development and direct commercial purchase stages, as they now do. Thus, it is necessary to plan well in advance for dual-usefulness, not only to promote rapid application of advanced technologies, but, more importantly, to make weapon systems affordable. Design changes after the R&D stage that are not met by concomitant capabilities in production or final assembly are extremely expensive.
- Ultimately, success with CMI will require DoD to "think outside of the box." This will include changing the procurement system so that it is more adaptable to commercial business approaches and opportunities.

II. COMMERCIAL-MILITARY INTEGRATION AND THE MARKETPLACE

The social process is really one indivisible whole. Out of its great stream the classifying hand of the investigator artificially extracts economic facts. The designation of a fact as economic already involves an abstraction, the first of the many forced upon us by the technical conditions of mentally copying reality.

—Joseph Schumpeter[1]

This chapter lays the foundations for assessing the economic efficacy of CMI, defined here as the production of commercially viable and militarily useful products using at least some shared resources at comparable costs. It builds on the existing literature by exploring what CMI will mean for firms that become involved in integration activities—a key question since integration will occur only to the extent that commercial entities succeed in pursuing profitable opportunities.

While not comprehensive by any means, this chapter offers a formal economic treatment of the theories of single and multi-product production as they pertain to firm behavior under a regime of integrated commercial and military production. Included are brief expositions of economies of scale and scope and a theoretical treatment of the characteristics of integrated markets. A ratio-accounting measure of the degree of CMI is offered at the end of the chapter as a first step toward developing empirical evidence for the degree and pervasiveness of CMI.[2]

A. CO-PRODUCTION AND CMI

While much of economic theory deals with enterprises as if they produce only one product at a time, in reality this is not the case. Within the past decade considerable discussion has focused on the importance of multi-product production, particularly how this affects the competitive nature of firms and market structure. However, while the

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1 Joseph Schumpeter, *The Theory of Economic Development*, 1989, p. 3.

2 The mathematical constructs contained in this chapter are for illustrative purposes only and are not derived from empirical studies. Rather, they are used as a descriptive "short-hand" by economists to produce an analytically rigorous framework for discussion.

ensuing debate is of considerable interest to academic economists, we are faced with a much more practical set of problems and must seek to extract an "operational" approach that may be applied to CMI. We proceed along a path similar to that elaborated by Baumol, Panzer, and Willig.[3]

1. Single Product Production

Suppose we produce a commercial good c with a cost function, $C(q_c)$, where q_c is the level of output. $C(q_c)$ is composed of a constant fixed cost C_f and a variable cost $C_v(q_c)$ that varies with the level of production. Let $R_c(q_c) = p_c q_c$ denote the revenue earned at price p_c, and quantity q_c.[4] Profits π will be:

$$\pi = R_c(q_c) - C(q_c) = R_c(q_c) - C_f - C_v(q_c) \tag{2.1}$$

Since revenues must cover total costs of production, $\pi \geq 0$. The average cost of producing a unit of q_c must therefore be less than or equal to average revenue, or price:

$$\frac{C_f + C_v(q_c)}{q_c} \leq \frac{R_c(q_c)}{q_c} \tag{2.2}$$

The first order condition for profit maximization may be found by differentiating C' with respect to q_c and setting it equal to 0:[5]

$$\frac{d\pi}{dq_c} = R_c' - C' = 0 \text{ or } R_c' = C',$$

$$\text{where } C' = C_v' = \frac{dC}{dq_c} \text{ is the marginal cost of production,} \tag{2.3}$$

$$\text{and } R_c' = \frac{dR_c}{dq_c} \text{ is the marginal revenue.}$$

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3 Baumol, Panzer, and Willig, *Contestable Markets and the Theory of Industry Structure*, 1988. For recent work on the impact of flexible manufacturing on market structure, see: B. Curtis Eaton and Nicholas Schmidt (September 1994), "Flexible Manufacturing and Market Structure," *American Economic Review*, 84, No. 4, pp. 875–88.

4 p_c need not be a constant. It is a function of the competitive structure of the industry. The variables that may affect p_c include q_c, the quantities produced by other firms in the market, the prices of substitutes and complements, etc.

5 To simplify the exposition, we will assume that for any optimization problem considered in this chapter, first order conditions are both necessary and sufficient, and define a unique solution to that problem.

If the industry is perfectly competitive, our firm is a *price taker* and sees p_c as a constant. Eq. (2.3) becomes price equals marginal cost, the well-known equilibrium condition from elementary microeconomics. In equilibrium the marginal cost for every firm in this industry will be equal to the equilibrium price.

Let p_c^* be the equilibrium price in the industry and q_c^* be the quantity produced by our firm in the absence of government procurement. Now suppose the government wishes to acquire δ units of this good, where δ is small relative to the commercial market.[6] We can consider two polar cases for the industry structure of c: perfect competition and monopoly.[7]

Under perfect competition, the government can always buy in the commercial market at price p_c^*. Can it do better by negotiating with individual suppliers? The answer is no. It would be irrational for any firm to sell to government at a price below p_c^* since it would be selling below marginal cost and losing money. Let p^g be the price the government pays:

$$p_c^* = p_c^g = C'(q_c^*) \qquad (2.4)$$

Under monopoly conditions, the commercial price is higher than the marginal cost at the monopoly quantity. This is because under monopoly conditions profit maximization occurs when price is set to average revenue, and therefore price exceeds marginal cost and marginal revenue.[8] This suggests that the firm would be willing to negotiate with the government for a price between marginal cost and the commercial price. The greater the government bargaining power, the closer the negotiated price will be to marginal cost:

$$p_c^* > p_c^g = C'(q_c^*) \qquad (2.5)$$

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6 The restrictions on δ are for convenience. They can be relaxed at the expense of clarity, but the results would remain roughly the same.

7 Methodologically, monopoly and perfect competition are the least controversial models of market structure. Despite considerable progress, the economics profession has yet to settle on a single/complete theory of oligopoly. In section 3.3.a, below, we consider a duopoly model with product differentiation and economies of scale. See Jean Tirole, *The Theory of Industrial Organization*, MIT Press, Cambridge, MA, 1987, for a formal treatment of these issues.

8 Henderson and Quandt, *Microeconomic Theory*, 1971, pp. 208–215.

In practice this can occur only when the government possesses information on the cost structure of the firm, and, hence, the need for cost accounting regulations/reporting requirements built into much of government procurement.[9]

2. Co-Production

Now assume that the firm produces two products, a commercial product (c) and a military product (m) useful only to the government. The cost of producing both products is defined by the joint cost function $C(q_c, q_m)$, while the costs of producing each product by itself can be denoted by $C(q_c, 0)$ and $C(0, q_m)$. In all cases C varies with output. Similar to the single-product firm, the profitability of a multi-product firm is its revenue minus its costs:

$$\pi = R_c(q_c) + R_m(q_m) - C(q_c, q_m) \qquad (2.6)$$

Note that a simple calculation of average production costs is no longer meaningful without a priori restrictions on the mix of output.[10] This is because there is no single product to act as the denominator. This may be overcome by assuming that the firm produces a "composite commodity," say 3 units of c and 2 units of m, but cost comparability across output levels breaks down if proportionality fails to hold.

The first order conditions for profit maximization are analogous to the single good case:

$$\frac{\partial \pi}{\partial q_c} = \frac{dR_c}{dq_c} - \frac{\partial C}{\partial q_c} = 0 \qquad (2.7a)$$

$$\frac{\partial \pi}{\partial q_m} = \frac{dR_m}{dq_m} - \frac{\partial C}{\partial q_m} = 0 \qquad (2.7b)$$

Eq. (2.7b) assumes that the revenue function for m is well defined. But, as in Section 1, above, R_m may be subject to negotiation between the government and the firm, and Eq. (2.7b) would not then be meaningful. A question that naturally arises is, what is the lowest price, p_m^*, at which the government will be able to procure δ units of m? The answer is fairly straightforward: the government must set a price high enough

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9 The corollary is: if a supplier has no market power, the government gains nothing by imposing costly reporting burdens.

10 See Baumol et al., *Contestable Markets*.

that a firm could earn as much profit from selling m to the government as it could not selling m (not selling m in this case is equivalent to selling c). To find the *reservation* profit level for the firm, we first determine $\tilde{q}_c$, the equilibrium quantity produced if the firm refuses to sell to the government, i.e., the solution to (2.7a) when we set $q_m = 0$:

$$\frac{dR_c(\tilde{q}_c)}{dq_c} - \frac{\partial C(\tilde{q}_c, 0)}{\partial q_c} = 0 \tag{2.8}$$

Setting profits from producing m equal to that attainable not producing m yields:

$$\begin{aligned} &p_m^* \delta + R_c(q_c^*) - C(q_c^*, \delta) = R_c(\tilde{q}_c) - C(\tilde{q}_c, 0) \\ &p_m^* = \frac{R_c(\tilde{q}_c) - C(\tilde{q}_c, 0) - R_c(q_c^*) + C(q_c^*, \delta)}{\delta} \end{aligned} \tag{2.9}$$

q_c^* may be characterized by rewriting (2.5a) with $q_m = \delta$:

$$\frac{dR_c(q_c^*)}{dq_c} - \frac{\partial C(q_c^*, \delta)}{\partial q_c} = 0 \tag{2.10}$$

Eq. (2.8), (2.9), and (2.10) together solve the government's cost minimization problem (assuming that it has all of the bargaining power). But what are their practical implications? The most important one is that they completely characterize the information needed to achieve the optimum. Unlike the single-good case, this is a fairly complex requirement. With a single good, knowing the marginal cost (or simply the commercial price under perfect competition) is sufficient for the government to achieve its best price. With co-production, the government needs to know the firm's profits (and costs) under a hypothetical scenario that may never be observed. It also needs much more precise information about the cost structure of the firm (in particular the interaction between both types of goods and, therefore, how to allocate shared costs). Before dismissing these points as merely theoretical considerations, note that this is the conundrum that Defense Department auditors encounter when assessing the "value to the government" of products co-produced for military use. There is no unique way in which to allocate the production costs by share of productive asset. This is further complicated when so-called economies of scope from co-production enter the picture.

3. Economies of Scale and Scope

In the economic literature the notion of economies of scale is considered elementary, although such economies are the subject of much debate regarding their impact on the structure of markets. Economies of scope, while acknowledged throughout much of the history of economic thought, are less tractable to study and their impact on the behavior of firms more controversial.

Economies of scale are said to exist for that portion of the production function where the average costs of production decline. If sufficiently large relative to the market, they may put a restriction on the number of firms that can operate profitably in the industry. If such economies are experienced throughout the full range of production possibilities, then the most efficient way to serve the market would be with a single firm, a *natural monopoly.*

Economies of scope are said to exist when two goods can be produced more cheaply together (co-production) than separately. A firm that has unused capacity in the production of one product may therefore benefit by producing another product to share the underutilized capabilities.[11] Or, a firm may consciously seek to exploit similarities in products to reduce costs common to both. In this second case, a scale economy opportunity may enter into the equation if the cost of more capable, shared production assets is less than other, less capable unshared production assets.

The following brief discussions of scale and scope economies are intended to demonstrate some of the many factors that should be considered in assessing the possible effects of government CMI policies on competitive markets.

a. Scale Economies

Scale economies are important in understanding the behavior of firms that supply military needs since they imply that a contract awardee may gain a cost advantage over its competitors. In such a case, firms bidding on government contracts would be seeking to reduce their overall average costs of production on "identical" items offered in both commercial and military markets. The effect of the government entering commercial markets may have some unintended consequences.

Consider, for instance, a situation in which a market for the commercial good *c* has two firms, A and B, each of which experiences scale economies in their production processes. A natural monopoly has yet to arise because of a variety of factors, including product differentiation, brand loyalty, and perhaps anti-trust laws. From the point of view of the commercial market, the goods produced by A and B are imperfect substitutes

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[11] A classic example of economies of scope is the co-production of leather and beef where leather is a by-product of processing beef.

with the price of each good influencing the demands for both itself and its competition. Each firm sets price to maximize profits given its competitor's price.[12] The government is faced with choosing one or the other producer to provide its commercial item for military use. We further assume that the products of A and B are differentiated for commercial purposes, either will serve equally well for military purposes.

Without going into too much detail, it is sufficient to note that in equilibrium (without any government purchases), the two firms will set their respective marginal revenues equal to their marginal costs. Now (as in the earlier sections) suppose that the government wishes to procure some δ units of c. There are two cases to consider. First, suppose that the cost functions of the firms consist of a fixed cost and a *constant* marginal cost (marginal cost is invariant to output level—a non-standard assumption we use here as a heuristic). The economy of scale is due solely to the firms' abilities to amortize the fixed cost over larger quantities of production. If the government awards a procurement contract to one of the firms, will this action affect the outcome in the commercial market? The answer is no! The equilibrium remains unchanged because *neither the marginal revenue nor the marginal costs of either firm is affected by the government procurement.* The prices and quantities in the commercial market that maximized profits without the government purchase still maximize profits.

The second *type* of economy of scale assumes that as the level of production rises not only do average costs decline but marginal costs do as well. Figure II-1 illustrates how a firm's marginal cost curve (as a function of commercial purchases) changes when it is selected to produce for the military.

Under these conditions, it is easy to see that the neutrality result from the previous case no longer holds. Producing for the military *lowers a firm's marginal costs* (as a function of commercial purchases). In equilibrium, with the government as a purchaser, the firm producing for the military will now set a lower price and sell a larger quantity of its product in the commercial market, while its competitor will be forced to lower prices, but not by a sufficient amount to offset its loss in sales. The intuition is as follows.

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12 This is known as *Bertrand competition* under product differentiation.

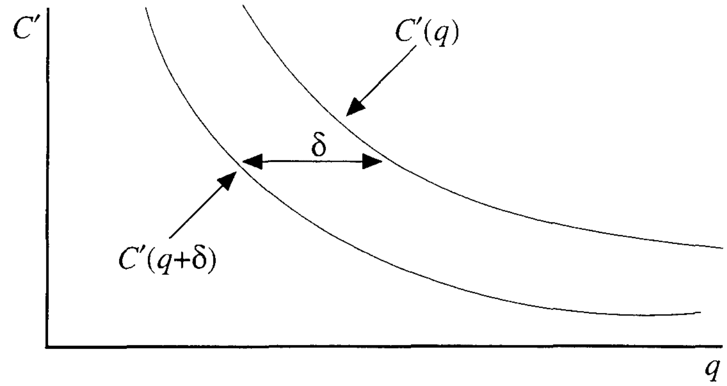

Figure II-1. Marginal Cost With and Without Military Buy

Under these conditions, it is easy to see that the neutrality result from the previous case no longer holds. Producing for the military *lowers a firm's marginal costs* (as a function of commercial purchases). In equilibrium, with the government as a purchaser, the firm producing for the military will now set a lower price and sell a larger quantity of its product in the commercial market, while its competitor will be forced to lower prices, but not by a sufficient amount to offset its loss in sales. The intuition is as follows.

For the firm with the government contract, marginal revenue in the commercial market exceeds marginal cost when compared with the set of equilibrium prices prevailing without government purchases. Lower marginal cost creates an incentive to lower price. Conversely, for the firm without the government contract, a lower equilibrium market price brought on by government purchases from the competing firm leads to a downward shift in the marginal revenue curve so that the firm's marginal cost now exceeds its marginal revenue. The firm not selling to the government is led to both lower prices and reduce output. If the cost advantage conferred by government sales is sufficiently large, then the commercial-only firm may even be forced to exit the market.

To complete the analysis we need to look at how the government might go about awarding the procurement contract and how that might affect the nature of inter-firm competition. One interesting result arises if the contract is auctioned off. Under such circumstances it is possible that both firms are made worse off. The following examples shed light on how this may arise.

For simplicity let two firms face identical demand and cost schedules. Under such conditions competition would lead to an equilibrium bid for the procurement contract where the winner and the loser end up with the same profits.[13] We have demonstrated above that the firm that loses the contract will receive smaller profits because of the downward shift in its demand curve. Thus both firms, in order to avoid coming in last, will bid so that both will have lower profits!

The above result is sensitive to the auction process and the fixed price nature of the contract. Instead, now suppose the government randomly selected one of the two firms (since they are equally proficient) and sets the price equal to average cost. We have already shown how the marginal cost of a firm shifts as a result of producing for the military. Under this reimbursement rule, marginal revenue also changes because altering how much a firm produces for the commercial market still affects the price the government pays. Economies of scale mean that average cost declines as output rises. Since the government's price is pegged to average cost, as the firm increases commercial sales, the price the government pays goes down. This creates a countervailing effect on the winning firm's desire to increase output in the commercial market.

Up to this point we have assumed that a commercial market actually exists. Another interesting case to think about is one in which a new technology has some commercial potential but is not produced commercially because of high production costs/low demand. If a military application should develop, purchases by DoD could have the effect of bringing the new product to the market. Consider the following example.

Let the cost function for the new technology be $C(q_c) = C_f + mq_c$, where C_f is the fixed cost and m is the constant marginal cost. Let the inverse demand function be $p_c = a - bq_c$. Let $a > m > 0$, $b > 0$. Revenue can be denoted by $(a - bq_c)q_c$. Setting marginal revenue equal to marginal cost yields $q_c = (a-m)/(2b)$, the profit maximizing quantity. A little algebra gives us the condition on C_f so that profits will never be positive for any $q_c > 0$ and therefore no production takes place:

[13] Let b be the winning bid. If ex-post profits were not equal, the firm with the lower profits could put in a bid equal to either $b - \varepsilon$ or $b + \varepsilon$, where ε is some small value, and raise its profits.

$$
\begin{aligned}
&p_c q_c - C_f - m q_c < 0 \\
&\left(a - b\frac{(a-m)}{2b}\right)\frac{(a-m)}{2b} - C_f - m\frac{(a-m)}{2b} < 0 \\
&\left(\frac{a+m}{2}\right)\frac{(a-m)}{2b} - C_f - m\frac{(a-m)}{2b} < 0 \\
&C_f > \frac{(a-m)^2}{4b} = \pi_o
\end{aligned}
\tag{2.11}
$$

π_o is the maximum operating profit that the firm can earn. Therefore, if π_o does not cover fixed costs, the firm will not enter the market. Assume that Eq. (2.11) is met and that, therefore, no commercial market exists. If the government wishes to acquire δ units of the good, the highest price it must pay is $\left(C_f + m\delta\right)/\delta$, the average cost without any commercial sales. Note, however, that at such a price, the firm has covered its fixed cost and can now profitably enter the commercial market. At the above military price the firm earns a positive profit equal to π_o. Setting profit equal to zero, it follows that the minimum price the DoD may pay is:

$$
\begin{aligned}
&R_m + \pi_o - C_f - m\delta = 0 \\
&p_m\delta + \frac{(a-m)^2}{4b} - C_f - m\delta = 0 \\
&p_m = \frac{C_f}{\delta} + m - \frac{(a-m)^2}{4b\delta}
\end{aligned}
\tag{2.12}
$$

The relative price between the military and the commercial market is determined by how close to equality Eq. (2.11) is. If C_f is very large, then Eq. (2.12) tells us that the military will pay a higher price. On the other hand, if the opposite is true, then:

$$
\lim_{C_f \to \frac{(a-m)^2}{4b}} p_m = m \tag{2.13}
$$

At the limit, the military price approaches marginal cost, which is less than the (monopoly) price paid in the commercial market. Note that in both cases the military price is lower than what the government would have to pay if commercial opportunities were nonexistent.

b. Scope Economies

Scope economies may also affect the competitive balance of markets under certain circumstances. While average costs of production cannot be calculated for each product within a co-production process, total costs can be calculated. Following Baumol et al.,[14] we define economies of scope as:

$$C(q_c, q_m) < C(q_c, 0) + C(0, q_m), \ \forall\, q_c, q_m > 0 \qquad (2.14)$$

Co-production opportunities arise when existing production inefficiencies lead to the underutilization of some productive assets for single-product production. Such single-product "inefficiencies" may be regarded as opportunities by consciously seeking co-production possibilities during the planning stages for new products. Alternatively, opportunities may arise when a market is saturated, leaving capacity either unused or underemployed.

CMI will necessarily involve co-production of commercial and military products. Pricing products emerging from such activities for both commercial and defense consumers is problematic, as discussed earlier. If economies of scope exist, then marginal cost pricing will not be indicative of resources expended in the production of the different items, and average costs are indeterminate without a priori fixing output levels.

As with scale economies, scope economies may also have unintended impacts upon competitive markets. For instance, awarding the co-production of a product to a contractor may lead to overall production cost advantages so that competitors may be forced to leave the market.

Consider the cost function we developed in the previous section. If the cross-partial derivative is negative, then economies of scope exist:

$$\frac{\partial^2 C}{\partial q_c \partial q_m} < 0 \qquad (2.14a)$$

Eq. (2.14a) simply says that as the production of one product rises, the marginal cost for the other product falls.[15]

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14 Baumol, et al., *Contestable Markets*, p. 71.

15 Eq. (2.14) is sufficient, but not necessary, for economies of scope.

Let us set up a model identical to that considered above for economies of scale except that each firm possesses a cost function exhibiting economies of scope that satisfies Eq. (2.14a). First, note that in the absence of any government demand for m, the equilibrium outcome is solved in an identical fashion: each firm sets its price so that marginal revenue is equal to marginal cost. Now suppose the government awards a contract for δ units of m for some fixed price to one of the firms. Just as before, the marginal cost schedule (as a function of q_c) for the winning firm shifts down and it raises output and lowers prices in the commercial market. The qualitative results in this case are identical to those under economies of scale. In fact, with some minor modifications, the remainder of the analysis in the previous section also applies here. In particular, economies of scope can, in some instances, induce commercial firms to produce for the military, and in other cases, induce military producers to enter commercial markets and as a consequence lower prices for the military.

From the government's point of view, and in particular that of DoD, economies of scope from co-production are particularly attractive since they promise to leverage commercial capabilities for military purposes. Beyond the issue of "fair" pricing to the government, however, there are complex issues regarding the coordination of requirements between the private and public sectors in the development, planning, and execution phases for new products. The success or failure of CMI will therefore hinge not only on issues of pricing, but also on the willingness of DoD to make co-production opportunities attractive investments for commercial firms.

Hence, while economies of scale appear attractive for commercial firms because they offer an opportunity for them to enter into the production of military products, scope economies are difficult to characterize from an equity standpoint. True, there are parallels in common with economies of scale, but the added difficulties encountered when attempting to allocate costs between two different products that share some common processes may offset these benefits.[16] In particular, the behavior of firms under a regime of co-production is not totally predictable since an increase or decrease in the demand for one of the goods may lead to radical changes in the composition of output.

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16 This is an argument that the costs of measuring and monitoring the activities may outweigh any efficiency gains from economies of scope.

B. MEASURING THE DEGREE OF COMMERCIAL-MILITARY INTEGRATION

Conceptually, we have considered CMI as the production of commercial and military products together, where the degree of integration is determined by the commonalty of the production techniques employed. This has both theoretical and practical implications. In theory, each phase of the production process may be defined so that it is possible to determine whether it is used exclusively to produce the military or commercial product, or jointly to produce both. Each such discrete phase of production, or "stage," serves as an accounting mechanism for determining the amount of integration achieved. In practice, few accounting systems yet have this capability, although so-called "activity based costing," or ABC, offers an approach conformable to such measurement needs.[17]

For the moment let us assume that the necessary accounting conventions exist in a single facility where two different products are produced, a commercial product c and a military product m. These products share some common resources in their fabrication, but also have individual attributes that differ. Therefore, some stages of production are different for each. By aggregating the costs associated with producing a single unit of c and m, we can establish a metric that conveys the amount of shared resources employed relative to the total resources used to produce both. Table II-1 gives an example of such a production process.

In Table II-1 we have two production processes, one for m and one for c. Both have been broken down into discrete production stages, some of which are in common (stages 1, 2, and 5) and some which are not (stages 3 and 4). The cost of producing a single unit of c and m is w_{ci} and w_{mi}, respectively. Can we offer a quantitative measure of the "integratedness" of these production processes?

[17] For an introduction to ABC see: Michael C. O'Guin., *The Complete Guide to Activity Based Costing*, 1991.

Table II-1. Production Costs at Defined Stages

Production Stage (i)	Input Cost($) w_{ci}	w_{mi}
1	10	10
2	20	20
3	----	20
4	10	----
5	10	10
Total	50	60

We are looking for a measure of CMI that offers comparability across a variety of production processes for different products. It is also desirable to construct one that has intuitive appeal so that it may be easily understood. From the data in Table II-1, it is possible to construct one such measure which ranges from zero (0), for complete absence of CMI, to one (1), where complete CMI is attained. Mathematically it is expressed as:

$$\text{CMI index} = \frac{\sum_{k \in \{F_c \cap F_m\}} (w_{ck} + w_{mk})}{\sum_{i \in \{F_c\}} w_{ci} + \sum_{j \in \{F_m\}} w_{mj}}, \tag{2.15}$$

where F_c and F_m denote, respectively, the production stages utilized in the production of the commercial item and the military item.

This simply says that the costs in common to both the production of a unit of c and a unit of m should be summed, and this sum divided by the sum total unit cost of producing each. Applying this to the data in Table II-1 we obtain:

$$\frac{w_{c1} + w_{c2} + w_{c5} + w_{m1} + w_{m2} + w_{m5}}{w_{ctotal} + w_{mtotal}} \tag{2.16}$$

Based upon our example this yields a CMI Index of $80/($50 + $60), or 0.7272.

Clearly, if c and m had no production stages in common, the numerator is zero and thus our CMI index is zero. If all stages are in common, the numerator and denominator would be equal, yielding an index of one.

While the CMI index offers a means of quantifying the degree to which commercial and military co-production takes place, it alone is not sufficient to measure the efficiency of such operations. This requires an understanding of the *optimal* level of CMI from both a commercial and defense (public policy) point of view. The following example illustrates this point.

Suppose that a firm has been funded by the U.S. government to undertake research and pilot production of a new composite material with important military attributes. Even though research results are promising and a defense market exists, commercial markets are not large enough for the material to allow the enterprise to remain in production and achieve a rate of return attractive to private sector investors. Hence, in order to ensure the supply of the material the government is faced with the following dilemma.

To maintain production of the material a subsidy must be applied to ensure profitability. Since there are some commercial markets, sales to the private sector keep the level of the subsidy moderate. Furthermore, since the composite material is produced using identical processes for both commercial and military uses, the CMI index is close to and approaching one.

Even if the CMI index is almost unity, government intervention continues to be required to keep the enterprise afloat. Is this a case of successful commercial-military integration? According to the definition of CMI given earlier, no. That is, because the effective price which the government pays to the enterprise is different (higher) than that in competitive markets, in effect the composite is not commercially viable. Hence, neither co-production nor a high value for the CMI index, alone or together, indicate that CMI efforts have been successful since nonmarket institutional factors may remain that must be present to affect commercial acceptance.

C. OBSERVATIONS ON THE ECONOMICS OF CMI

The increasing dual-use nature of many technologies does not necessarily imply the disappearance of all or even the majority of defense-specific production activities. Rather, it suggests that in many instances fewer distinctions between the process technologies employed in the production of military and commercial systems and components could be brought about through conscious decisions on the part of the military. Properly addressed, this would allow DoD to take advantage of commercial economies of scale and scope, as well as other efficiencies through the co-production of products in the same facilities, and in some cases on the same production lines. It would also follow that the performance of a greater number of commercial sectors of the economy would become "directly" defense relevant.

A common misunderstanding that arises, however, is the notion that private industry will flock to co-produce military and commercial products. As elaborated above, this will be true only where the rate of return on investment from co-production exceeds that of commercial production alone. It is said that Hewlett-Packard and Caterpillar simply refuse to bid on government contracts because the anticipated rate of return is not high enough to warrant their attention, and they find procurement practices and standards bothersome and inefficient. This leads us to question the rationales that would attract commercial firms to engage in dual-use pursuits.

In particular, the economics of CMI demonstates that government must make it worthwhile for commercial firms in the private sector to pursue doing business with DoD. In so doing, however, the government must take care not to upset the balance of the marketplace through its actions. Particularly in cases where strong scale or scope opportunities are likely there is a need to avoid driving out competition by giving any one firm an edge over another. The purpose of CMI is to take advantage of efficiencies spawned in a competitive marketplace, not to create inefficiencies through ham-handed policies and inadvertent monopolies.

Even with the full cooperation of commercial firms, pursuit of co-production opportunities will continue to be troublesome if the government does not reform the way it does business with the private sector. This is not merely an issue of regulations. Rather, the culture of commercial industry must be learned, and where possible adopted, so that government practices become harmonized with those in the competitive marketplace. When undertaking this task the government must recognize that it will fail to attract world-class capabilities in a global marketplace if its practices are not capable of keeping pace with or allowing the full realization of efficiencies by transnational firms.

This chapter has attempted to depict the sound, rational economic decisions that profit-maximizing commercial firms will make regarding industrial base integration. Where advantages may arise through the increased use of excess production capacity, such as through co-production, or from expanded scale of operations, subject to the elimination of costly nonmarket barriers, private sector investments will be made. Outcomes of firms competing for business in an integrated commercial-military industrial environment will then depend on the approaches taken by government policy makers when competing for contracts, as well as other business and economic factors in the global economy.

On the matter of assessing progress towards industrial base integration, in some ways this issue will be moot if future government competition and acquisition policies are constructed to "harmonize" with commercial best practices. That is, adherence to market principles should lead to "optimal" integration without additional interference from the public sector. However, given the need to rationally monitor progress for auditing and reporting purposes, we have offered a simple device which quantifies the degree of integration.

D. SUMMARY

- While much of economic theory deals with enterprises as if they produce only one product at a time, in reality this is not the case. In fact, multi-product production is particularly important in determining the behavior of firms and may affect their relative competitiveness as well as market structure.
- Under a regime of single-good production, knowing the marginal cost (or simply the commercial price under perfect competition) is sufficient for the government to achieve its best price. With co-production, the government needs to know the firm's profits (and costs) under a hypothetical scenario that may never be observed. It also needs much more precise information about the cost structure of the firm (in particular the interaction between both types of goods and, therefore, how to allocate shared costs).
- Economies of scale are said to exist for that portion of the production function where the average costs of production decline. Economies of scope are said to exist when two goods can be produced more cheaply together (co-production) than separately.
- From the government's point of view, and in particular that of DoD, economies of scope from co-production are particularly attractive since they promise to leverage commercial capabilities for military purposes. Beyond the issue of "fair" pricing to the government, however, there are complex issues regarding the coordination of requirements between the private and public sectors in the development, planning, and execution phases for new products. The success or failure of CMI will therefore hinge not only on issues of pricing, but also on the willingness of DoD to make co-production opportunities attractive investments for commercial firms.
- Unfortunately, while economies of scale appear attractive for commercial firms because they offer an opportunity for them to enter into the production

of military products, scope economies are difficult to characterize from an equity standpoint. In particular, there is the significant problem of equitably allocating costs between two different products that share some common processes. The behavior of firms under a regime of co-production is also not totally predictable since an increase or decrease in the demand for one of the goods may lead to radical changes in the composition of output.

- It is possible to construct a measure indicative of the degree to which co-production leads to CMI. This requires accounting conventions, such as Activity Based Costing (or ABC), which allow identification and assignment of cost according to production stage. Nevertheless, even if a CMI index reports a high degree of integration, successful commercial-military integration has not occurred if government intervention continues to be required to keep the enterprise afloat. According to the definition of CMI given earlier, the price that the government pays to the enterprise would be different than that in competitive markets; in effect, the product would not be commercially viable on its own. Hence, co-production alone does not guarantee that CMI efforts have been successful.

III. COMMERCIAL-MILITARY INTEGRATION AND GLOBAL COMPETITION

Today, technological capabilities are much more widely distributed throughout the globe than they were 10 or 20 years ago. In this new multi-polar technological order, the activities of multinational corporations have contributed to the emergence of a trans-national technology base in a growing number of industries. As a result, it is becoming increasingly difficult to distinguish one firm's technology from another's or one nation's technology base from another's.

—National Academy of Engineering, 1991[1]

In the mid-1970s, the technological capabilities of our allies and adversaries began to equal and in some cases surpass our own. By the end of the 1980s foreign commercial and military technology developments were challenging U.S. security interests in a broad range of areas, including software and systems engineering, radar sensor technology, acoustics, microelectronics, manned space, and human systems.[2] Some argue that these developments were aided by foreign government policies that treated technology, economics, and national security issues concurrently from an integrated perspective—a willingness to view national security interests and the commercial marketplace as interdependent, where overall national well-being, economic and military, is seen as part of a mutually supporting framework for pursuing national goals.[3] [4]

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1 National Academy of Engineering, *National Interests in an Age of Global Technology*, 1991, p. 72.

2 U.S. Department of Defense, *DoD Key Technologies Plan*, 1992. These are areas reported in the 1992 Defense Key Technology and compared in that document with the capabilities of allies and former adversaries.

3 This was particularly evident in Japan as documented in the writings of Chalmers Johnson, Daniel Okimoto and Clyde Prestowitz. Chalmers Johnson, *MITI and the Japanese Miracle: The Growth of Industrial Policy*, 1925-1975, 1982. Daniel Okimoto, *Between MITI and the Marketplace: Japanese Industrial Policy for High Technology*, 1989. Clyde Prestowitz, *Trading Places: How We Are Giving Our Future to Japan and How to Reclaim It*, 1989. Also see: Clyde Prestowitz, *Powernomics*, 1991.

In Europe, cooperative research in both the defense and civil arena has existed during the post-W.W. II period for the express purpose of promoting joint technological capabilities in support of economic performance and security. In addition to EC-92 and transnational cooperation on military and civilian aircraft designs, the Europeans are cooperating in information technology (ESPRIT), microelectronics (JESSI), industrial technology (BRITE), advanced communications (RACE), and so forth. See, for

Technology, however, is but one dimension of "national competitiveness." Without skillful management, strategic planning, and the creation of new market opportunities, simply creating the most advanced technologies cannot ensure that a nation or its economic agents—commercial businesses—will attain or retain world leadership. In particular, firms involved in the CMI process must become globally competitive in order for a world-class military capability to arise from the dual-use technologies they create. The continued "globalization" of economic activities suggests that inward-looking national competitiveness policies are unlikely to produce firms that are capable of yielding requisite commercial and dual-use capabilities.

This chapter reviews some of the broad economic issues regarding the international competitive environment in which CMI investments are being undertaken. This type of a review is essential to understanding what may and may not be accomplished with such investments. Up to this point our discussions have effectively treated the economics of CMI under autarky—as if the United States were economically self-sufficient and did not engage in trade. Obviously, the effects of government policies will be different for autarkic economies than for permissive trade economies. The following discussions highlight the differences we expect to observe under a regime of permissive trade.

Given the expansive literature on globalization, we first discuss features common to the works reviewed in an attempt to characterize the underpinnings of the increasingly integrated international marketplace. We then address the issue of how the changing nature of inter-firm collaboration on a global basis, alliance formation, and "out-sourcing" have become pivotal to achieving world-class-best competitive results and the implications for CMI of rapidly changing global competitive circumstances. This leads to recent work on the subject of national competitiveness and the role of the firm. This discussion focuses on two apparently contradictory trends observed in the international

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instance: National Academies of Science and Engineering, *Europe 1992: The Implications of Market Integration for R&D-Intensive Firms*, 1991.

4 A variety of writings also address the role of government in promoting a competitive national economy. See, for instance: Nelson and Gavin Wright, "The Rise and Fall of American Leadership: The postwar Era in Historical Perspective" *Journal of Economic Literature*, December 1992. Kash and Rycroft, "Nurturing Winners with Federal R&D," *Technology Review*, Nov/Dec 1993. James E. Gover, "Strengthening the Competitiveness of U.S. Microelectronics," *IEEE Transactions of Engineering Management*, February 1993. Leyden and Link, *Government's Role in Innovation*, 1992. Kenneth Flamm, "Semiconductor Dependency and Strategic Trade Policy," *Brookings Papers: Microeconomics 1993*, pp. 249–333.

competitive arena—one towards geographic concentration, the other towards geographic dispersion—both of which are touted by different authors as at the heart of the competitiveness equation. Finally, we conclude with a general discussion of the strategic importance of globalization for CMI and U.S. security policy in general by reviewing the concept of "market foreclosure."

A. DEFINING GLOBALIZATION

Although the term "globalization" is used liberally by representatives of government, business, and academe, it has no unique definition. Over the past decade a literal cottage industry has arisen, producing books, papers, reports, and studies on the concept. To better identify just what is meant by globalization for this paper, we reviewed a variety of works dealing with trade and international competition/collaboration, including those of Michael Porter, Robert Reich, Lester Thurow, Robert Kuttner, James Brian Quinn, Clyde Prestowitz, Theodore Moran, and Laura Tyson, as well as studies by the National Academies and independent boards and commissions.[5]

Within this literature there is general agreement that the essence of globalization is the proliferation of cross-border business and supplier relationships that form the backbone for international technological and industrial exchanges of information, financial support, and know-how. Such exchanges are said to be the basis on which a truly integrated world economy will emerge in the future. However, no two discussions of this vast topic yield identical results.

For our purposes, we need a definition of globalization that corresponds to defense interest in promoting an integrated industrial base. In the context of CMI and dual-use technologies, globalization should be viewed as: *a process of integration where the research, development, engineering, production, and marketing of military*

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5 Robert B. Reich, *The Work of Nations: Preparing Ourselves for 21st Century Capitalism,* 1991. Michael Porter, *The Competitive Advantage of Nations*, 1990. Robert Kuttner, *The End of Laissez-Faire: National Purpose and the Global Economy After the Cold War.* 1991. James Brian Quinn, *Intelligent Enterprise*, 1992. Lester C. Thurow, *Head to Head: The Coming Economic Battle Among Japan, Europe, and America,* 1992. Howard M. Wachtel, *The Money Mandarins: The Making of a Supranational Economic Order,* 1986. Theodore H. Moran, "The Globalization of America's Defense Industries: Managing the Threat of Foreign Dependence," *International Security*, Summer, 1990, pp. 57–99. National Academy of Engineering, *National Interests in an Age of Global Technology*, 1991. National Academy of Engineering, *Technology and Global Industry*, 1987. National Academy Press, *Globalization of Technology: International Perspectives*, 1988. Laura Tyson, *Who's Bashing Whom?*, 1993. Clyde Prestowitz, *Trading Places: How We Are Giving Our Future to Japan and How to Reclaim It*, New York: Basic Books, Inc., 1989.

equipment, systems, and their components, including dual-use products,and processes, increasingly occurs across national boundaries worldwide. The continuation and growth of this system of internationally dispersed, yet interdependent production relies upon the following four conditions:

(1) *Permissive Political Regimes.* The existence of globalization today and in the future would be impossible without a continuation of post-Second World War international permissiveness in the areas of trade and monetary policy. Without this "fabric" of bi- and multilateral treaties and agreements it is impossible for firms to enter into enforceable cross-border contracts, guarantee prices, or seek compensation for the improprieties of others.

(2) *Cheap, Unfettered Transportation.* Competition between producers of different nations has become possible largely because of advances in transportation technologies. Large bulk commodity carrying vessels have made access to raw materials from far-flung corners of the world real and affordable possibilities. Conversely, containerships, unit trains, trucking, and advances in air freight have allowed the cheap distribution of consumables, durables, and intermediate industrial goods.

(3) *High-Capacity Telecommunications.* Advances in telecommunications have brought about the potential for truly integrated international markets through improvements in interconnectivity, enabling the proliferation of industrial and technological links. Today corporations are able to command resources worldwide from a single location, and an integrated international banking and financial system offers enormous potential for investment and reallocation of resources. Advances in data exchange capabilities and the standardization of product and process information protocols indicate the potential for a complete global distribution of manufacturing and intellectual endeavors.

(4) *Flexible Business Practices.* Firms are rapidly adapting their organization and management to conduct business in a truly international marketplace. This entails broadening their understanding of who the competition is, reevaluating what constitutes state-of-the-art and "world-class" business and industrial standards, and reexamining national affiliation. This process will continue to be important in the future since it is not yet clear what the tension between the transnational character of firms and the geographic responsibilities of individual governments will yield.

So long as these four conditions characterize international economic relationships firms can no longer be viewed as geographically constrained in their pursuit of increased competitiveness and profitability. Research, development, production, marketing, and finance may be accomplished using the best mix of business and technical resources that may be assembled worldwide.[6]

In the context of commercial-military integration, globalization foreshadows dramatic changes that will lead to a transnational system of military production as well. The complex sets of relationships that today comprise international commerce will render obsolete traditional approaches to describing defense industries within a hierarchy of prime and sub-contractors. To understand the evolution of the defense and commercial industrial bases towards global integration, we briefly take up the issues of global collaboration and competition among firms.

B. GLOBAL COLLABORATION AMONG FIRMS

The more global economic and technological endeavors become, the less appropriate it will be to view defense production activities as a simple pyramid of companies engaged in producing and assembling components and parts to yield a completed weapon system. This is already true domestically because weapon system designers and producers are no longer necessarily the same at any level of fabrication or assembly. Under a global production regime, weapon system design will not be the responsibility of one firm or a small set of firms; rather, it is likely to be dispersed worldwide to take advantage of technical specialties of many participants. This may also occur for fabrication, assembly, and research and development activities should the level of interconnectivity mature sufficiently.

Such arguments lead to a conception of global defense industrial activities within the context of grand endeavors cutting across national boundaries. The global dispersion

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6 Reich, *The Work of Nations*, 1991. Reich focuses on the proliferation of cross-border corporate relationships and internationally based businesses which he terms "global webs." These webs comprise "computers, facsimile machines, satellites, high-resolution monitors, and modems—all of them linking designers, engineers, contractors, licensees, and dealers worldwide," p. 111.

Porter, *The Competitive Advantage of Nations*, 1990. Porter emphasizes the extension of the competitive character of differing national economies based upon factor endowments, technologies, domestic markets, and national tastes. These differences have led to a global economic system where "a nation's competitive industries are not spread evenly through the economy but are connected . . . [by] . . . clusters consisting of industries related by links of various kinds," p. 131.

Quinn, *Intelligent Enterprise*, 1990. Quinn emphasizes the importance of out-sourcing business activities where it is not possible to achieve world-class capabilities in-house, particularly in the service industries.

of design and production activities introduces new and critical issues for the success of commercial-military integration and the development and deployment of advanced, affordable weapons and systems for the U.S. military. Defense industry globalization suggests that profit-making enterprises will seek competitive advantages by relying on the lowest-cost sources worldwide, regardless of geographic location. Firms that do not engage in such efficient forms of collaborative behavior will not survive in the global marketplace.

Cross-border collaborative business relationships represent different types of foreign influences, from those that may be voluntarily encouraged to those that are coerced. The degree to which such relationships may adversely affect national security depends on the nature of the cross-border relationship, the availability of alternative domestic capabilities, and whether or not foreign firms are acting openly. Since intense competition is promoting alliances, and many of these alliances contain or will contain large, transnational corporations, careful attention must be paid to "extended" teams—indirect beneficiaries of U.S. government dual-use investments. To facilitate discussion of the various cross-border relationships we have categorized them as foreign sourcing, cross-border alliances, and foreign direct investment.

1. Foreign Sourcing

Foreign sourcing by defense industries may be broadly characterized as the use of foreign-supplied components, items, or processes for the production of weapons systems. We may distinguish foreign sourcing from foreign dependence in that domestic suppliers are available but not used. Whether or not citizen-owned offshore activities are "foreign" is itself a topic of constant discussion.

From the *businessman's* point of view, foreign sourcing is simply a matter of relying on foreign firms for the research, development, marketing, or production of products, components, or technologies. Unlike businessmen, U.S. defense planners regard the use of foreign firms to supply the military with great concern since it is critical that conflict-related production demands be met in the event of war. From a narrow national security point of view only domestically based, domestically owned sources of supply are truly "secure"; some may argue, however, that any domestically based firm is secure regardless of ownership.

The importance of foreign sourcing to national security is a function of its positioning within the overall regime of weapon system production. Security concerns related to foreign sources' delivery of finished weapons systems must be distinguished from those associated with the delivery of components or the conduct of research and development. Furthermore, the temporal characteristics of the weapon system's production must be considered to determine overall sensitivity.

Consider the case of long lead time weapons, a category which includes virtually all high technology arms. For short duration conflicts, stockpiling finished systems and repair/replacement components could allow a nation to field foreign-produced items with little if any risk to overall national security.[7] Regardless of where production takes place, the additional quantity of arms that may be produced is unlikely to arrive in time to be militarily significant. For lower tech materiel with shorter lead times that are not likely to be stockpiled in large quantities, such as battle dress uniforms, chemical suits, and meals ready to eat (MREs), a domestic source may be deemed important to provide flexibility and ensure continued supplies. Conversely, if long-term conflicts are anticipated where foreign supplies are uncertain, there is no adequate replacement for domestic production capabilities.

While foreign sourcing may not pose immediate threats to national security, in the long run considerable problems may arise if the development of new military technologies moves offshore along with production. In such a case the defense technology infrastructure may erode, leading to the deployment of less capable systems in the future. Additionally, foreign weapons producers benefit from the expatriation of research and development, allowing potential U.S. adversaries to field more capable weapons of their own.

The United States, for instance, is today becoming technologically "vulnerable" to the foreign policies of its current allies—Europe and Japan. While much of the concern is the product of political hyperbole, such as Shintaro Ishihara's claim that "without using new-generation computer chips made in Japan, the U.S. Department of Defense cannot guarantee the precision of its nuclear weapons,"[8] longer term concerns may be real. For instance, the Defense Science Board in 1989 expressed worries about increased U.S. dependence on "foreign" produced integrated circuits: only 25 percent of DoD integrated

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7 See Chapter I.

8 Shintaro Ishihara, *The Japan That Can Say No*, 1989, p. 21.

circuits are manufactured onshore; most "piece parts" going into integrated circuit fabrication other than the die are produced offshore; and "95% of all Standardized Military Drawing (SMD) die are produced in offshore facilities owned by U.S. firms."[9]

In the long view, a balance needs to be struck between the clear cost and technical advantages that may accrue from employing foreign production and technological capabilities, and the loss of domestic technical know-how and skills that occurs when production or research is moved offshore. If only short wars with short warning times are anticipated in the future, the optimal approach would be to minimize the degree to which the United States pursues "arsenal" policies when clearly superior foreign capabilities may be procured.

2. Cross-Border Alliances

Another manifestation of globalization is the cross-border corporate alliance, defined here as virtually any cooperative venture or activity between domestic and foreign firms, be it in research, production, marketing, etc. Such alliances are perhaps the greatest indicator of the growing global nature of today's defense industrial base and are not simply first-world phenomena.

The European approach to defense production, for instance, may be best characterized as "on-again, off-again" cross-border alliances initiated by governments to meet the large resource requirements of high technology weapons systems development. Such alliances led to the development of the Alpha Jet, Jaguar, and Tornado aircraft. The European Fighter Aircraft (EFA) is a joint development program involving the U.K., Germany, Italy, and Spain. EFA, in fact, is heralded as "the biggest collaborative defense program ever undertaken by NATO, with "[r]adar . . . to be provided by GEC Marconi of the U.K., avionics and cockpit displays by GEC Avionics and Smiths Industries of the U.K., weapon interfaces by MBB of Germany, V/UHF communications subsystems by Rohde & Schwartz of Germany, while Alenia of Italy and CASA of Spain had secured numerous contracts for other subsystems.[10] The goal is to develop a technological synergy to deliver capabilities beyond those of any one of the partners.

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9 Defense Science Board, *Use of Commercial Components in Military Equipment*, Mimeo, July 1989, p. 6.

10 Nick Cook, *Janes Defense Weekly*, 21 March, 1992, p. 480.

Alternatively, Japanese military production has tended to rely on a series of co-production and licensing agreements with the United States for its high technology weapons systems, although within the past decade it has also begun to apply its considerable commercial technological capabilities to meet national defense needs.[11] For instance, Japan sought permission to increase the number of aircraft it is allowed to produce under license from the United States, including the Bell/Fuji AH-1S and Sikorski/Mitsubishi SH-60J/UH-60J helicopters, the McDonnell-Douglas/Mitsubishi F-15J fighter, and the Lockheed/Kawasaki P-3C Orion aircraft.[12] In addition, it is producing moderate quantities of indigenously designed air-to-air missiles based on U.S. systems, including the AAM-3, SAM-1 and Keiko SAM.[13] However, behind the willingness to enter into co-production agreements is an active government effort to apply foreign military technologies to commercial pursuits. In this regard the FSX, an indigenous Japanese fighter aircraft that is derivative of the U.S. F-16, is viewed by some as primarily a technology transfer ploy to support an incipient Japanese commercial aircraft industry.

Today, some newly industrializing countries and some less developed countries have also joined developed nations in demanding co-production of weapon systems they are purchasing from abroad. For instance, U.S. co-production of the F-16 includes Belgium, Turkey, Israel, South Korea, Indonesia, and the Netherlands.[14] Additionally, General Dynamics agreed to assemble 50 complete F-16 aircraft under license in South Korea as part of a competitive sales enticement for that nation. Argentina and Egypt have cooperated in the development of the Condor ballistic missile, apparently aided by MBB of Germany.[15] Taiwan has sought the aid of U.S. defense firms to develop its Indigenous Defense Fighter,[16] while Chile is cooperating with Royal Ordnance of the U.K. to develop a truck-mounted rocket artillery system.[17] The United States has even expressed

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11 Office of Technology Assessment (OTA), *Arming Our Allies*, 1990, p. 66.

12 *Aviation Week and Space Technology*, 13 April 1992, p. 11.

13 OTA, *Arming our Allies*, 1990, p. 66.

14 OTA, *Global Arms Trade*, 1991, pp. 42–43.

15 W. Seth Carus, *Ballistic Missiles in the Third World: Threat and Response*, 1990, p. 22.

16 Paul Proctor, "First IDF Delivered as Taiwan Spools Up for Full Production," *Aviation Week and Space Technology*, 1992, pp. 38–39.

17 Christopher F. Foss, "UK-Chilean Rayo Test Launched," *Janes Defense Weekly*, 22 February 1992, p. 281.

interest in obtaining a wide range of Commonwealth of Independent States (C.I.S.) military technologies to avoid costly duplication of research. All of these arrangements lead, to some degree, to technology transfer as well as the training of foreign nationals in the production and integration of military systems.[18]

From a national security standpoint, cross-border corporate alliances entail the same potential threats and benefits as foreign sourcing. In addition, however, it involves more intensive technology transfer activities, particularly in the process of establishing qualified production facilities in other nations. On the one hand, this may be viewed as a considerable threat to national security since both classified and proprietary information is made available to other nations, and there are the ever-present risks of intentional transfer of knowledge to potential U.S. adversaries. On the other hand, such activities do offer advantages that should not be ignored.

When a U.S. company sets up shop to produce weapon systems and their components overseas in allied nations, the advantages for national security come in several forms. One is the degree to which foreign markets may become amenable to the purchase of U.S. arms, a development which, in turn, increases the volume of production and lowers overall unit costs. Another is the potential for system interoperability worldwide with allied nations who maintain support and repair facilities usable by U.S. forces. The use of foreign qualified suppliers to provide for U.S. defense needs in times of national emergency—a literal extension of the U.S. defense industrial base—should also not be overlooked. And as foreign technology developments demonstrate world-class potentials, U.S. firms should not be proscribed from availing themselves of potential advantages for commercial and military purposes.

3. Foreign Direct Investment

If a company is unable to access a technology, capability, or product through license, co-production, or foreign sourcing, it may resort to investing in or acquiring another firm, an option referred to as "foreign direct investment." In recent years foreign acquisitions of U.S. firms in particular have taken center stage because of increased Japanese activities oriented toward buying U.S. real estate and entertainment industry assets. These business transactions are part of the considerable foreign investment in the

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[18] "Cooperating with foreign industry in the development and production of weapons builds up their indigenous defense industrial capabilities, transferring potent, advanced defense technology to foreign nations." *Global Arms Trade*, p. 13.

United States in the past decade which totaled $15.2 billion in 1984, peaked at $72.7 billion in 1988, and was last reported at an annual rate of $64.4 billion in 1990.[19] In the case of non-military relevant companies the U.S. government has regarded such activities as benign.

The national security implications are more troublesome, however, when the foreign acquisition involves a defense-relevant firm engaged in first or second tier military production. For example, when a consortium that included Thomason-CSF of France and the Carlyle Group of the United States tried to acquire the missile division of LTV Corporation, the U.S. government believed that the security of U.S. missiles systems could be compromised even if separate managements were set up to make ownership influence "arms length." The acquisition would have included the Theater High Altitude Air Defense, Multiple Rocket Launch, and Army Tactical Missile Systems, as well as components for the B-2 bomber.[20] A prospective deal involving the purchase of 40 percent of McDonnell Douglas by Taiwan Aerospace Corporation also had national security overtones.[21] In both situations the U.S. government intervened to prevent potential technology transfer to other nations.

The negative implication of foreign direct investment for U.S. national security, therefore, is the potential loss of control over the entire spectrum of the development of selected weapon systems, their components and associated research. This concern is founded on the belief that foreign-owned, domestically based corporations owe their allegiance to their home nations and may somehow be coerced away from cooperating with the United States. There is also concern that technologies and secrets may be repatriated against the wishes of the U.S. government, or that experience gained by foreign corporations producing U.S. weapon systems will be applied offshore.

Investors seeking to acquire or control U.S. defense firms see things quite another way. They argue that their investments support, or in some cases sustain, the U.S. defense industrial base. Particularly in an era when defense spending is declining

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19 Mahnaz Fahim-Nader, *Survey of Current Business* (Washington, DC.: U.S. Department of Commerce, U.S. GPO), May 1991, p. 30. Amounts are in nominal dollars.

20 Frank C. Carlucci, *Aviation Week and Space Technology*, 8 June 1992, p. 66; *International Defense Review*, May 1992, pp. 403-4.

21 Velocci, *Aviation Week and Space Technology*, pp. 26-7.

internationally, consolidating defense companies across national boundaries affords efficiencies in operation, production, and research overhead. Furthermore, there is the real possibility that foreign firms may bring to U.S. weapon system production manufacturing techniques and product technologies that are not available domestically.

C. GLOBAL COMPETITION AMONG FIRMS AND CHOICE OF LOCATION

In the 1994 March/April issue of *Foreign Affairs*, the well-respected international trade economist Paul Krugman published a contentious article highlighting his belief that some policy makers in the current administration, and others, misunderstand the nature of competition among nations.[22] This misunderstanding, he implied, stemmed from a view that nations compete economically the same way they compete militarily. Krugman's point was that economic competition is different from military competition since it occurs between firms, not governments. This was not to deny the existence of national policies that might play a role by conferring nonmarket advantages on one or more agents,[23] but rather to emphasize that economic strategies cannot be formulated and exercised like military campaigns, particularly in a global economy where transnational corporate activities are fast becoming the norm.

While Krugman's views are certainly not new to the economics profession, they represent but one side of an increasingly complex public policy debate. On the other side, for instance, Clyde Prestowitz is representative of those who would argue that government assistance is essential to maintaining the international competitiveness of firms.[24] He asserts that nations that do not conform to U.S. "free" market principles, including those where so-called "nonmarket" barriers are erected, should be challenged to liberalize their trade regimes through aggressive U.S. foreign policies and domestic programs targeted at promoting industries deemed to figure prominently in the national interest, such as semiconductors, consumer electronics, and flat panel displays.[25]

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22 Paul Krugman, "Competitiveness, A Dangerous Obsession," *Foreign Affairs*, March/April 1994, pp. 28–44.

23 The recent U.S. government intervention on behalf of Motorola in Japan is a clear example of such government influence over international markets.

24 Clyde Prestowitz Jr., "The Fight Over Competitiveness: A Zero-Sum Debate: Responses," *Foreign Affairs*, July/August 1994, pp. 186–203.

25 Note that as part of the current administration, Reich might also be placed under this banner. However, his *Work of Nations*, in actuality is more a call to improve the national resources available to U.S. firms, particularly labor, rather than an argument for trade intervention, subsidies, or tax breaks.

While the debate about the true character of international competition is broadly relevant to national security, it would be neither fruitful nor possible to address all of the issues that global interactions raise for CMI. Rather, we focus on an important subset dealing with the geographic location of research and production worldwide. This is particularly germane since it helps explain the location of world-class military capabilities which rely to the greatest degree possible on a domestic, integrated, dual-use industrial base. The role of government in helping to determine where production and R&D activities locate is central to understanding the potentially far-reaching effects of CMI policies. The challenge within a permissive trade environment is to achieve for U.S. firms competitive advantages that will result not only in technological advances, but also in long-term commitments to domestic operations.

Of the authors cited earlier in this chapter, Michael Porter most clearly addresses the issue of competitive advantages accruing from geographic concentrations of competitors, such as regions characterized by particular classes of industrial activities. He contends that such concentrations, along with other "national" resources, positively affect the global competitiveness of firms. Conversely, James Brian Quinn is most forceful in arguing that geographic location is losing significance with the growth of interconnectivities afforded through the four foundations of globalization—permissive governments, telecommunications, transportation, and flexible business practices. We pursue and reconcile these apparently contradictory lines of argument below to arrive at an understanding of the determinants of enterprise location.

1. Porter's Thesis—Regional/Local Competitive Advantages

Michael Porter argues that empirical evidence, in the form of extensive case studies, leads to the conclusion that an important factor determining the world-class competitiveness of firms is the geographic concentration of similar, competing economic activities. Such activities appear to arise around unique natural or man-made "resources" concentrated within particular regions of the globe.[26] Examples of natural resources are

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[26] Porter, *The Competitive Advantage*, 1990. "Among the strongest empirical findings from research is the association between vigorous domestic rivalry and the creation and persistence of competitive advantage in an industry." p. 117. "Domestic rivalry, like any rivalry, creates pressure on firms to improve and innovate. Local rivals push each other to lower costs, improve quality and services, and create new products and processes. While firms may not preserve advantages for long periods, active pressure from rivals stimulates innovation as much from fear of falling behind as the inducement of getting ahead." p. 118. "Vigorous local competition not only sharpens advantages at home, but pressures domestic firms to sell abroad in order to grow. Particularly when there are economies of scale, local competitors force each other to look outward in the pursuit of greater efficiency and higher

local concentrations of a particular type of clay for pottery or ceramics, ore deposits, or fisheries. Examples of man-made resources are government-sponsored programs, educational activities, and transportation networks.

For CMI dual-use technology investments, man-made resources include university and government laboratory research that could attract high-technology, for-profit enterprises to a region. Apparent examples of positive externalities from such activities leading to new economic opportunities are the concentrations of high-technology activities in California (Silicon Valley), Massachusetts (Route 128), and North Carolina (Research Triangle). Biotechnology activities that have concentrated in recent years around the National Institutes of Health in Bethesda, Maryland, are also seen as confirmation of Porter's "regional" hypothesis.

Nevertheless, not all geographically concentrated research expenditures have led to beneficial regional economic concentrations. Counterexamples include Department of Energy and Defense laboratories, which generally have not attracted for-profit activities to their locales, primarily because nuclear and conventional weapons research and development activities to date have not aggressively targeted commercial applications (this may be changing, however).

Similarly, the existence of commercially relevant resources, natural or man-made, in a particular locale is in itself insufficient to produce world-class competitors, or even regional economic concentrations. Rather, competition between regions may lead to the migration of firms, and complementary, supporting commercial activities must be present to ensure that enterprises mature into successful competitors. Furthermore, governments at all levels vie to attract firms to move within their geopolitical boundaries, and such distortions may override other resource considerations.

In short, governments making conscious attempts to promote regional concentrations to improve the competitiveness of firms face great uncertainty. Porter recognizes this when he argues that there is little evidence to suggest that significant changes can be

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profitability." p. 119. "Toughened by domestic rivalry, the stronger domestic firms are equipped to succeed abroad. It is rare that a company can meet tough foreign rivals when it has faced no significant competition at home," p. 119. "Domestic rivalry not only creates pressures to innovate but to innovate in ways that *upgrade* the competitive advantages of a nation's firms. The presence of domestic rivals nullifies the types of advantage that come simply from being in the nation, such as factor costs, access to preference in the home market, a local supplier base, and costs of importing that must be borne by foreign firms." p. 119.

wrought with limited regional investments.[27] In many cases, regional concentrations arose because of a confluence of favorable factors. Where they were instigated by public investments they have succeeded when coordinated with existing resources and market opportunities. There is no a priori reason to believe that competitive regions may be "germinated" as seedlings and expected to compete with other global "flora" and "fauna." Rather, if geographic synergies are contemplated as part of dual-use investment strategy, appropriate investments would seek to leverage promising regions that have demonstrated the ability to organize around one or more technology foci where there are already significant levels of commitment.

2. James Brian Quinn—Core Competencies and Outsourcing

The writings of James Brian Quinn also address the competitive nature of firms in the global marketplace. Contrary to Michael Porter, Quinn contends that the factors enabling globalization to continue are also stimulating a new set of business diversification/divestiture practices leading to geographically dispersed production activities which function with greater efficiency than those centrally located.

As noted at the beginning of this chapter, communications, transportation, flexible business practices, and permissive political regimes are leading to greater opportunities for firms in the international marketplace. According to Quinn, such opportunities are not only in the purchase and sale of goods and services, but also for the "sourcing" of business capabilities as well. From within the milieu of the "virtual corporation," this author argues that in order to remain globally competitive a firm must avail itself of so-called world-class best practices. Those in-house activities which a firm supports, therefore, must either become world-class or be discontinued and replaced by external sources. Only world-class capabilities will lead to the greatest competitive edge, and if these lie outside the firm, they may be purchased or procured more cheaply than they can be produced internally.

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27 Ibid. "[G]eneralized factors are not a sufficient basis for national advantage in advanced industries, they serve as the foundation from which advanced and specialized factors are created. Sustained national investment in generalized factors is therefore essential to national economic progress. . . . What is important for competitive advantage is unusually effective mechanisms for creating and upgrading factors that are advanced and specialized, such as a world-class research institute in composite materials technology." p. 157. "Geographic concentration of firms in internationally successful industries often occurs because the influence of the individual determinants in the "diamond" and their mutual reinforcement are heightened by close geographic proximity within a nation. A concentration of rivals, customers, and suppliers will promote efficiencies and specialization."

The question, then, is what should be retained in-house? The answer is core competencies.[28] These are distinguishing capabilities that define the firm—areas in which it excels and has a strong probability of achieving world-class status. It is such competencies around which firms build their customer bases. In the future, the notion of a successful firm without a world-class core competency will be oxymoronic.

Combining these three sets of characteristics (globalization, out-sourcing, and core competencies) paints a picture of the future in which competition among firms may take place worldwide, virtually independent of geographic considerations. Of course in the case of natural resources, or perhaps less mobile inputs such as labor or large fixed investments, proximity will continue to be a factor. But to the extent that there will exist many different sources for substitutable goods and services, the need for "closeness" will become increasingly irrelevant.[29] Furthermore, given the ability of new technologies to overcome or obviate natural resource constraints, complete geographic independence may some day be achieved.

Dual-use investment policies based on the Quinn characterization of global competition would therefore seek to leverage technological resources worldwide to incorporate world-class capabilities into weapon systems and their production. Instead of pursuing national policies to provide domestic capabilities for all aspects of military production, foreign sourcing would become an integral part of the overall integration strategy. In this way it would parallel, or "piggy-back," observed commercial developments in many high technology areas. Such policies would need to be tempered to some degree, however, to ensure that a qualitative differentiation continued to exist between U.S. and foreign weapons and systems. This could be achieved through support of activities to augment or advance commercial designs and capabilities for specific military employments, an issue to which we return, below, when discussing market foreclosure and strategic dependence.

3. Dispersion Versus Concentration—Unraveling the Contradiction

We have characterized the above theses about the origin of competitive advantage in an admittedly extreme fashion to offer a contrast. Both theories are based on observations and trends in the global marketplace. That each purports to reveal the

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28 Quinn, *Intelligent Enterprise*. Prahalad and Hamel, "The Core Competence of the Corporation," *Harvard Business Review*, May-June 1990, pp. 79–91.

29 *21st Century Manufacturing Enterprise Strategy*.

observed nature of international competition among firms appears a contradiction. The explanation for this is not difficult to see.

During the past decade advances in interconnectivity, which includes both communications and transportation, have allowed efficient geographic dispersion among dependent production and development activities of firms. This is a shift from more traditional approaches to achieving intra-firm efficiencies through concentration in specific locations. What is observed by Quinn, therefore, is the ability to conduct enterprise operations among interdependent business units over great distances. A firm focusing on core competencies alone will embrace not only virtual business practices, but also out-sourcing in areas where other firms demonstrate greater or world-class efficiencies.

However, in some cases there may never be sufficient interconnectivity to achieve desired transfers of knowledge and know-how. This is particularly true today in the R&D arena, where the capabilities of a research or design team may benefit from close human interactions, including "having lunch" and "taking in a brew." Such circumstances also exist as a result of "tacit knowledge," where not all aspects of a process or product are committed to paper or may be transmitted electronically. Porter, for instance, mentions that chance meetings of entrepreneurs and researchers at popular restaurants are important to the informal flow of information that leads to new ideas and endeavors.[30]

Combining the two theses reveals a spectrum of geographic concentration ranging from the complete dispersion represented by virtual enterprises to very tight regional groupings of specialized, tacit knowledge activities. Dispersion results as world-class opportunities are pursued globally as part of out-sourcing beyond core competencies; regional concentrations arise where synergistic effects among geographically proximate firms offer competitive advantages over dispersed locations. The complete picture is a system of world-class geographically concentrated "resource nodes" globally sourced by firms as part of routine competitive practices.

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[30] See Porter, *The Competitive Advantage*, p.120: "A group of domestic rivals tries alternative approaches to strategy and creates a range of products and services that cover many segments. . . . The stock of knowledge and skill in the national industry accumulates as firms imitate each other and as personnel move among firms. . . . Geographic concentration of rivals in a single city or region within a nation both reflects and magnifies these benefits. . . . In such an environment, popular luncheon spots are patronized by executives from several companies, who eye each other and trade the latest gossip. Information flows with enormous speed. Though any one firm must move fast to sustain its advantage, the whole national industry is dynamic and sustains, or even widens, its advantage over foreign rivals who lack the same structure."

In fact this appears to be exactly what is transpiring in the arena of international arms production. It now involves not only competition among firms, but also collaboration in the form of alliances, investments, and international sourcing of technology and resources. For national security the issue therefore becomes one of pursuing a strategy which takes the greatest advantage of all aspects of world-class commercial capabilities regardless of location, and combines this with nationally unique and militarily specific developments to create the desired qualitative edge.

We learned above, however, that a strategy which seeks to base military needs on globally sourced commercial industrial capabilities is likely to be incompatible with policies that attempt to mandate domestic production. Such mandates ultimately constrain firms from taking advantage of efficiencies in the global marketplace and are commercially self-defeating. That is, to stimulate economic activities which will lead to internationally competitive industries or clusters of industries it is not sufficient to simply extend general forms of government assistance. Rather, there needs to be a systematic targeting of particular technology resources such as research and development activities, university programs, and industrial centers of excellence, along with general improvements in infrastructure and human resource support.

D. MARKET FORECLOSURE

Much of the alarm over the increasing globalization of technology and manufacturing competence revolves around the shrinkage and outright disappearance of certain domestic hi-tech industries. Prominent examples are microelectronics lithography and flat panel displays. From the point of view of national defense, many feel that relying totally on foreign suppliers to produce critical components leaves the United States vulnerable to supply disruptions during wartime.[31] Proponents of this view argue that, where this risk is particularly acute, the government may be wise to subsidize and support a domestic capability in the relevant area.[32]

We concluded in the previous sections of this chapter, however, that greater reliance on foreign sources of supply and production is inevitable as the world's

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[31] Moran, "The Globalization of America's Defense Industries."

[32] This does not mean that subsidization is necessarily the best way of ensuring an adequate supply. For example, stockpiling (e.g., strategic petroleum reserve, national defense stockpile of critical and strategic materials) and fostering other foreign suppliers may be far less expensive ways of accomplishing the same goal.

economies become more integrated. The issue becomes one of identifying when foreign production or sourcing is a threat to national security, and when it should be treated "benignly" as part of the global industrial base. Such assessments rest as much on an understanding of the market dynamics for a particular product or process as with its technical characteristics. In particular, the possibility that foreign suppliers may discriminate against American manufacturers on price or availability is cause for concern for both military and economic security.

The question is, when would a foreign supplier find it advantageous to discriminate against American suppliers? To illustrate this consider a stylized example of what economists term "market foreclosure."[33] Market foreclosure is defined as the actions a monopolist takes to restrict a buyer's access to a supplier, or a supplier's access to a buyer. Take the case of a monopolistic supplier, otherwise known as *upstream foreclosure*. Suppose that a monopolist produces an intermediate good, computer chips—one that is ultimately incorporated into a final product, personal computers. If there are several buyers of chips who compete in the computer market, is there an incentive for the monopolist to enter into an alliance with one of the firms or, alternatively, to restrict the sale of his product to only one firm?

In such an instance it does make sense for the monopolist to integrate with one of the computer makers. The existence of competition between computer makers reduces their profitability which, in turn, places pressure on the monopolist to reduce the price of chips. By joining with one of the computer makers, or "integrating forward," the monopolist could eliminate competition in the product market and extend its monopoly power. In the context of globalization, such foreign control of upstream markets may therefore eventually lead to the loss of downstream markets as well.

Note that this scenario goes beyond simple conceptions of monopoly power to entertain the notion that firms with sizable market shares may be able to undertake strategies to control the dynamics of downstream production and competition. For flat panel displays, for instance, a foreign firm's domination of a militarily important segment

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33 See Jean Tirole, *The Theory of Industrial Organization*, MIT Press, Cambridge, MA, 1987, pp. 193–198, for an overview of the literature on market foreclosure. A classic example of market foreclosure is that of the telephone industry prior to the breakup of AT&T. AT&T had a monopoly on local service but had to compete with, among others, MCI and Sprint for long-distance service. AT&T's competitors had to hook into AT&T's local networks. It is easy to see that if AT&T set transfer prices sufficiently high, it could drive its competitors out of business. Consequently, in order to ensure competition in long-distance service, one could not permit AT&T to freely set the transfer prices for hooking into its local networks.

of the market not only poses a supply disruption threat, but also puts in place incentives for the firm to eliminate competitors downstream who may be in a position to offer cost savings or quality improvements to DoD. This could manifest itself in an unwillingness to undertake research for important market niches, refusal to offer customized products, as well as pursuit of commercial goals which conflict with national security exigencies.

Recently, proponents of government support for a domestic flat panel display industry have made such arguments.[34] They assert that the collusive nature of industries in Japan allows a few national producers to control the entire world market for flat panel displays and that this may lead to the monopolization of downstream industries to the detriment of both American industry and American consumers. By giving priorities or price breaks to Japanese producers, Japanese industry can put American producers that use flat panel displays at a disadvantage, and in the extreme, force them out of their markets.

Note that all of this is predicated on the upstream market being monopolized. The fact that all the suppliers of an intermediate good are foreign is neither necessary nor sufficient to justify government intervention. If the upstream market is competitive, such as the competition between Japanese and Korean suppliers of memory chips, then the foreclosure argument outlined above does not follow and the fact that there are no domestic suppliers may be irrelevant. (From a purely competitive point of view, however, issues about technological externalities will still remain.)

Hence, an alternative strategy to subsidizing domestic producers may be to promote foreign alliances with non-Japanese firms that will ultimately be counted on as a counterbalance. Such a strategy could be used to promote a so-called commodity market, where a product becomes sufficiently standardized and generic that it may be sourced from numerous competitors.

E. OBSERVATIONS

The increasing dual-use nature of many commercial technologies coupled with defense industry globalization means that international business relationships and inter-dependencies increase the ease with which militarily relevant technology becomes available. At the same time, such relationships also increase the foreign content of U.S.

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34 Department of Defense, *National Flat Panel Display Initiative*, April 28, 1994, p. 8.

weapons systems directly and indirectly.[35] To be successful, CMI strategies must avail themselves not only of domestic opportunities, but also of the growing stock of new commercial technologies being developed worldwide that have dual-use potential. Particularly in an era of tight defense budgets and the increasing relevance of commercial technologies to the efficient and affordable production of weapons systems, a central tenet of CMI policy must be to make every effort to support only those activities that promote world-class potential. This should be pursued regardless of the extent to which U.S. and foreign firms are increasingly engaged in cross-border alliances, dependent on foreign sources, or acquired by foreign entities. Such interdependencies will only deepen and broaden in the future as long as permissive trading practices between nations endure.[36]

For commercial industry, the degree to which global distribution of production activities may take place will be a function of telecommunications and transportation to substitute for proximity. There are no a priori reasons to assume that with sufficient resources research, design, development, and production activities cannot be distributed globally. For instance, the commercial Boeing 777 aircraft is being produced through subcontracts to foreign firms, with design integration and final assembly taking place in the United States. Distributed design and production for military aircraft has been amply demonstrated in the cases of several European aircraft, including the Alpha Jet, Jaguar, and Tornado. Even for some equipment in the U.S. inventory, such as the F-16, foreign production of parts and components is a reality.

To provide for national security, the U.S. military needs to build upon world-class commercial capabilities wherever possible, including activities that offer unique, non-commercially available capabilities as quality multipliers. Hence, while promoting dual-use technology investments, militarily unique investments will also remain indispensable.

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35 For a discussion of existing evidence of the U.S. military dependence on foreign sources see: Erland H. Higenbotham, Peter B. Almquist, Harold E. Bertrand, Herbert R. Brown, John P. McHale, Joseph M. Ruzzi, George Sorkin, and Stephen N. Wooley, *Dependence of U.S. Defense Systems on Foreign Technologies*, IDA Paper P-2326, December 1990.

36 It should also be noted that the increasing globalization of the defense industrial and technology base—the spread of first tier production to less developed countries and newly industrializing countries and the greater integration of second and tertiary tier producers—poses significant challenges to U.S. policy makers. In particular, the United States must not allow itself to become positioned so that it is vulnerable to supply disruptions. Conversely, global interdependencies in trade and defense will tend to reduce the degree to which the U.S may pursue the "carrot and stick" approach to international relations. In cases where other nations act in ways that are antithetical to the interests of the United States, potential reactions by allies and adversaries in the context of foreign commercial and military dependencies must be weighed prior to taking action.

Commercial capabilities properly leveraged will thus lead to more affordable military systems, and at the same time free up budget resources to pursue specific military applications.

F. SUMMARY

- In the context of CMI and dual-use technologies, globalization should be viewed as a process of integration where the research, development, engineering, production, and marketing of military equipment, systems, and their components, including dual-use products, increasingly occur across national boundaries worldwide.
- Globalization is possible today because of the confluence of four tenets upheld by the international community: (1) permissive political regimes, (2) cheap, unfettered transportation, (3) high-capacity telecommunications, and (4) flexible business practices.
- Under a global production regime, weapons systems design will not be the responsibility of one firm or a small set of firms; it is likely to be dispersed worldwide to take advantage of technical specialties of many participants. This may also occur for fabrication, assembly, and research and development activities should the level of interconnectivity mature sufficiently.
- Cross-border collaborative business relationships represent different types of foreign influences, stemming from those that may be voluntarily encouraged to those that are coerced. The degree to which such relationships may adversely affect national security depends on the nature of the cross-border relationship, the availability of alternative domestic capabilities, and whether or not foreign firms are acting openly.
- Foreign sourcing offers potential advantages and disadvantages for U.S. security. On the one hand it offers access to a broader range of potentially dual-use technologies, many times at a fraction of the cost of developing them domestically. On the other hand, foreign sourcing leads to an erosion of U.S. technological capabilities by limiting our experience with the development of these technologies.
- Cross-border alliances are a fact of life in the commercial world and lead to more intensive technology transfer activities than foreign sourcing, when qualified production facilities are established by U.S. firms in other nations. As such, these alliances could be viewed as a considerable threat to national security since both classified and proprietary information is made available to other nations, and there are the ever-present risks of intentional transfer of knowledge to potential U.S. adversaries. Advantages from such activities should not be ignored, however: foreign markets may become amenable to

the purchase of U.S. weapons systems; system interoperability worldwide with allied nations is promoted; foreign qualified suppliers may become a source for the U.S. military in times of extreme national emergency; and, foreign world-class technology becomes available for U.S. firms.

- Foreign direct investment also has its pluses and minuses for U.S. security. The negative implication of foreign direct investment for U.S. national security is the potential loss of control over the entire spectrum of the development of selected weapon systems, their components, and associated research and development. There is also concern that technologies and secrets may be repatriated against the wishes of the U.S. government, or that foreign corporations producing U.S. weapon systems will gain experience that will be applied offshore. Conversely, foreign investments support, or in some cases sustain, the U.S. defense industrial base, and there is the real possibility that foreign firms may bring to U.S. weapon system production manufacturing techniques and product technologies that are not available domestically.

- All of the arguments regarding competitiveness and national security in a global economy revolve around the issue of how to promote the "national interest." In turn, national interest is regarded as improving the welfare and security for a particular geopolity. In a capitalist, free-trade system, the location of firms and their productive activities determine welfare, not abstract notions about the competitiveness of the nation-state itself.

- There are two countervailing tendencies characteristic of globalization today. One is the trend toward out-sourcing requirements to world-class producers without regard to location worldwide. The other is the apparent beneficial competitive effects arising from regional agglomerations of competing firms. In the future we could imagine a system of world-class geographically concentrated "resource nodes" sourced by firms globally as part of routine competitive practices.

- Globalization does not overcome the ability of one or more firms to "dominate" vital market segments and use derived market power to distort resource, product, or process availability.

- Ultimately, to provide for national security in a global economy the U.S. military must build upon world-class commercial capabilities wherever possible. It must also pursue activities that offer unique, non-commercially available capabilities as quality multipliers. Commercial capabilities thus leveraged will lead to more affordable military systems, and at the same time free up budget resources to pursue specific military applications.

PART 2

CHOOSING DUAL-USE INVESTMENTS TO PROMOTE COMMERCIAL-MILITARY INTEGRATION

INTRODUCTION TO PART 2

The process of choosing dual-use technology investments to promote CMI is much like deciding which health, education, transportation, or other socially beneficial projects should receive funding for other public purposes. The basic approach is to formulate a set of public policy goals, establish selection criteria with which to align proposed projects with such goals, and convene panels of experts to evaluate and recommend candidates for funding.

For some types of public investments it would appear to be easy to attach a dollar value to a project and incorporate "economic impact" information in the decision-making process. New highway construction, for instance, is usually amenable to such "hard" assessments since traffic flow is either known or reasonably projected. Similarly, new electric power utilities have well-defined monetary costs and associated revenue streams.

Even in such cases, however, effects that are much more difficult to quantify may bear consideration. A highway that alleviates traffic congestion may be a social good, but the resultant dislocation of neighborhoods, or perhaps noise pollution, has a negative impact outside the simple cost-benefit calculations pertaining to the highway itself. Conventional power utilities enable amenities that enhance our quality of life and support business activity, but they contribute to acid rain and greenhouse gases that may cause environmental damage.

Conversely, publicly financed projects may yield social benefits far beyond those originally targeted; e.g., research may lead to more effective vaccines, educational programs may improve economic and social opportunities, and defense technologies may also have commercial applications. A complete social welfare assessment should attempt to account for such benefits and costs, termed "externalities" by economists, even though they are not reflected in a project's monetary value. The problem is that the domain of these impacts may lie outside the system of prices provided by competitive markets, so subjective assessments in many cases are necessary.

All of this is germane to the evaluation of the economic impacts of investments in new technologies and technology support activities funded to promote CMI. Depending on a project's "time to market," it may or may not be possible *ex ante* to quantify its impacts on business or society. For some advanced technologies there is so little certainty of technical success or ultimate application that accurate a priori assessments are impossible; for educational programs impacts may be even harder to define. Even after a project is deemed successful and introduced in the marketplace in the form of new products, processes, or management paradigms, it may still be impossible to trace its ultimate impact back to earlier investments. However, since we have nothing but history with which to make assessments and choices, understanding the limitations of analysis, rather than blind reliance upon mechanical decision rules, still appears to be the key to a robust decision-making strategy.

This part of the paper examines the technical, private sector, and public sector rationales for project selection. The chapters build upon each other, beginning with the basic engineering and scientific basis for judging the relative superiority of a project, proceeding through business principles used in the private sector, and concluding with measures for assessing the social importance of a particular technology investment.

IV. THE TECHNICAL BASIS FOR INVESTMENT CHOICE

Over the past two centuries the economics profession has repeatedly addressed the question of how to best rank preferences among different sets of social choices. The result has been a set of formalisms and theorems that today constitute the "theory of choice," which seeks to uncover the logical foundations of "rational" decision making among alternatives or sets of alternatives. While this theory originated as an attempt to explain the behavior of individuals, it may also be extended to help us understand the behavior of a group of individuals acting in concert or in conflict. In the case of public decision makers involved in choosing technologies or technology support activities in which to invest, the theory of choice offers some basic insights which establish the boundaries for making inquiries into the nature and magnitude of economic impacts from investments. Such principles apply equally to all projects in which a choice between technical alternatives is necessary.

A. PAIRWISE TECHNICAL RANKING

Two different technology investment programs are under study, program A and program B, where the investment opportunities are part of the set S of all potential technology investments. Each program represents a subset of S and contains exactly the same number of investments to be made, but the projects in A and B differ in at least one case. Based on the evaluation of a selection panel the net social benefit of each program is determined. We will have one of three cases:

1) Program A is more beneficial than program B ($A > B$);
2) Program A is no more or less beneficial than program B ($A = B$); or
3) Program A is less beneficial than program B ($A < B$).

The basis for the panel's evaluation is, of course, our fundamental concern.

Suppose that the panel is composed solely of "technologists" from different disciplines and the potential technology investments are representative of these disciplines and not homogenous. Let us assume further that the only information on which to base decisions is physical in nature—economic impact projections and financial information are not yet available. The problem is, just how do the different technical achievements in A and B stack up against each other?

Begin with the simple case where all of the projects in A and B are identical save one. The project in program B but not in A, call it b, is one that has been identified by a materials expert as a significant accomplishment in storage cell technology. The project in program A but not in B, call it a, is one that has been identified by a communications expert as a significant accomplishment in high-speed network architecture. All of the other members of the panel are satisfied with the composition of the remaining projects, so the issue becomes one of comparing the importance of the battery project relative to that of the communications project.

It should be clear that armed with only the technical characteristics of the storage cell and communications projects, the panel will be unable to determine directly which will be more beneficial unless the basis for judging the two can be made comparable. That is, the metrics of technical achievement—in the storage cell's case perhaps capacity, or for the network perhaps transmission rate—must be judged on a common scale in order for a quantitative comparison to be made. The panel can accomplish this if it can formulate a transformation algorithm that both leads to a common quantitative measure of the two different project metrics and satisfies both the storage cell and network experts. But since each evaluator has a stake in making sure that the transformation selected favors their project, the transformation debate merely replaces the original metrics debate, so no analytical solution exists.

Now, suppose that there is direct comparability between two projects but more than one metric to be employed. If we label the metrics *1* and *2*, we will have an unambiguous answer to which program is better only if:

case 1: $a1 \geq b1$ and $a2 > b2$, so $a > b$ and $A > B$[1]

case 2: $a1 > b1$ and $a2 \geq b2$, so $a > b$ and $A > B$

case 3: $a1 \leq b1$ and $a2 < b2$, so $a < b$ and $A < B$

case 4: $a1 < b1$ and $a2 \leq b2$, so $a < b$ and $A < B$

In all other cases arguments may be made that the projects are at least equal. A transformation could be applied to measures *1* or *2* so that the preference of a over b is reversed, but this again requires consensus among the "contending" evaluators.

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1 Where $x \geq y$ is read as x is at least preferable to y.

While it would be desirable to find some way to avoid the technical choice problem altogether, this turns out to be impossible whenever resources are scarce and there are more good projects than dollars. In all such cases at least one project that has desirable characteristics must be excluded from funding. Conversely, if there is more money than there are desirable projects, there is no choice exercise at all, save agreeing on which subset of S will constitute the program.

Hence, choice based solely on technical measures, even when such measures are in common, generally is ambiguous. Project selection activities that rely solely on technical merit, therefore, employ so-called "experts" who must make informed judgments to come to closure. This raises the question, however, of how to combine the observations of the different participants involved in the selection process.

B. FAIRNESS AND RANKING IN SELECTION PROCESSES

It would be impossible in this paper to review all, or even a significant subset of, the literature dealing with voting theory and choice based on expert opinion. Instead, we focus on the principles around which such work is performed—the derivation of equitable results based on fair selection processes.

In the previous section we demonstrated that, when the metrics for ranking projects are not identical and cardinal, no definitive process for selecting among alternatives may be constructed. This does not relieve responsible officials of the burden of making choices. Two approaches that are generally used to conduct selection processes are voting and consensus, where consensus is here taken to be merely the general agreement among decisionmakers, involving no formal rules to arrive at closure.

The notion of voting as part of a selection process should not be confused with basic electoral processes, and unlike consensus it does involve formal rules which drive a decision process to closure. In a selection process, voting may involve weighting, point scores, and other conventions that purportedly signal not only whether a project is seen as favorable, but also just how much better or worse it is than other projects for which a ranking is being constructed.

Unfortunately, voting of all types entails the same problems that we identified with technical ranking, above. That is, while for an individual we may assemble an ordered ranking with one set of cardinal measures to identify the relative "goodness" of one project over another, this cannot be compared or aggregated with cardinal rankings of other individuals. There is no definitive basis on which to ensure that all of the individual rankings are comparable.

In fact, the difficulties facing decision makers seeking to "vote" on projects has been formalized by Arrow, who lists five reasonable conditions that one might wish to impose on a system of social choice rules. The Arrow possibility theorem[2] states that when three or more social outcomes are feasible, it is impossible to construct a performance ordering that satisfies all five of his conditions (see Figure IV-1). For our purpose, the requirements of this theorem may be seen as derivative of our discussions above.

Figure IV-1. Arrow Possibility Theorem (paraphrased)

Complete Ordering: There must exist a complete ordering of social preferences which is reflexive (if $A > B$ then $B \sim< A$) and transitive (if $A > B > C$ then $A > C$).
Responsiveness to Individual Preferences: If $A > B$ for society at large, and some individuals now raise their ranking for A, then it remains $A > B$.
Non-Imposition: Social preferences may not be imposed on individuals.
Non-Dictatorship: The preferences of society may not be dictated or reflective of any one individual.
Independence of Irrelevant Alternatives: The disappearance of an alternative shall not change the preference ordering of remaining alternatives.

First, there must be a way to order all choices so that no "reversals" occur. That is, if I prefer A to B and B to C, I cannot prefer C to A. Obviously, if such a circularity were to occur, then it would be immediately impossible to select one project over another. This is termed *complete ordering*.

Second, during a selection process if one individual should change his/her mind and increase the "scoring" for a project so that it is then ranked higher than other projects, we would like the aggregate ranking to remain unchanged. Here the rationale is that if

2 James M. Henderson and Richard E. Quandt, *Microeconomic Theory: A Mathematical Approach*, 1971, pp. 286-286.

the process is so sensitive to a single individual, then he/she is capable of exerting too much influence over the outcome. This is *termed responsiveness to individual preferences.*

Third, we would like to retain the independence of each of the individuals involved in the source selection process to protect them from the "will" of all other participants together. Otherwise the outcome will be reflective of the majority of the group and devoid of minority opinion. Note that this does not preclude influence by the majority based on reasoning and rationality, but eschews coercion. This is Arrow's *non-imposition criterion.*

Fourth, it is also important for a project selection process to avoid domination by one member of the group. The rationale here is the same as for point three, but in this case it avoids persuasion by a significantly prejudiced or opinionated person. This is the *non-dictatorship* condition.

Finally, a preference ranking should not be sensitive to the disappearance of one or more alternatives. If this is not the case, then there is no demonstrated independence of the alternatives, and as such no ranking of individual projects is possible. This *independence of irrelevant alternatives* is particularly difficult to achieve in cases where a series of projects is under consideration with multiple, but not independent, paths.

Because of the extremely restrictive conditions for assuring that choices are made on a consistent and comprehensive basis, the Arrow Possibility Theorem is also referred to by many as the Arrow "Impossibility" Theorem. It is central to the issue of selection solely by voting according to technical merit because it demonstrates that, within a logical and rigorous framework for ranking the desirability of projects, the probability of arriving at definitive choices when funding is scarce is exceedingly small.

Perhaps the most important example of an attempt to apply Arrow's conditions to ranking choices is embodied in the Analytical Hierarchy Process (AHP). Here, decision makers individually rank all possible choices on a pairwise basis. A mathematical convention is then used to measure the degree of consistency with which such rankings actually correspond to the complete ordering condition. It is assumed that the other four conditions apply.

Unfortunately, AHP tends to suffer from three drawbacks, none of which are actual criticisms of its analytical rigor. First, when complete ordering is not strong, then the results are of dubious value. Second, in many cases AHP is combined with a priori weighting schemes, which themselves embody the drawback that some individual or group of individuals must make a decision on the order of magnitude of the weights. And, third, in many cases the results from AHP are counterintuitive in that they are rejected as undesirable outcomes when presented to the participating decision makers.

The preceding conditions regarding the ranking of the desirability of projects on a technical basis also apply to the comparison of the progress of projects where technical goals or underlying technologies differ. For instance, the Arrow Theorem tells us that the progress of a software development project cannot be compared with the progress of a composite materials project because the bases for comparison cannot be constructed according to its five conditions. For this matter, it is also unlikely that two software projects with differing end goals are comparable. At best, therefore, technical project assessments would rely on their performance relative to a set of *ex ante* goals as embodied in technical and financial milestones unique to the project.

Note that Arrow's Theorem is generalizable for all projects involving technical choice. For instance, for projects involving government technical assistance services, differing demographics of client populations, access to resources (e.g., proximity to universities or industrial concentrations), and complementary federal, state, or local activities may enter into the assessment "equation." For education programs, the quality of faculty and student body, technical focus, and integration with non-university industry/ technology activities may factor in project evaluation and assessment.

All of this brings us back to the issue of how best to conduct a technical project selection activity. In fact, the Arrow conditions are important to the results of any such selection process, but we may not wish to constrain ourselves to formalized voting, scoring, and independence of evaluators (although non-dictatorship is still desired). Most selection processes evade the constraints and difficulties imposed by attempts to quantify technical decision making by resorting to collaborative methods—so called consensus decision making. In fact, a consensus approach appears to serve a selection process better than formal, individual voting when the knowledge base of each participant differs and may be exchanged in a mutually beneficial way. Such intercourse, along with "horse-trading" among alternative projects to arrive at a consensus ranking, has therefore become the vehicle of choice of most government source selection processes.

C. SUMMARY

- Over the past two centuries the economics profession has repeatedly explored how to rank preferences among different sets of social choices. The result has been a set of formalisms and theorems that today constitute the "theory of choice." This theory seeks to uncover the logical foundations of "rational" decision making among alternatives or sets of alternatives which may be extended to help understand how to choose technologies and technology support activities in which to invest.
- One result is that choosing among projects based solely on technical measures, even when such measures are in common, generally leads to ambiguous results. Selection activities that rely solely on technical merit therefore employ so-called experts who must make informed judgments in order to come to closure.
- While expert choice is generally taken to be a robust approach to project selection, the specific approach to aggregating the observations is not straightforward and leads directly to considerations generally found under the heading of "voting theory."
- The notion of voting as part of a selection process should not be confused with basic electoral processes. In a selection process, it may involve weighting, point scores, and other conventions that purportedly signal not only whether a project is seen as favorable, but also just how much better or worse it is than other projects for which a ranking is being constructed.
- Unfortunately, voting is problematic. That is, while for an individual we may assemble an ordered ranking with one set of cardinal measures to identify the relative "goodness" of one project over another, this cannot be compared or aggregated with cardinal rankings of other individuals. There is no definitive basis on which to ensure that all of the individual rankings are comparable.
- Arrow lists five reasonable conditions pertinent to voting that one might wish to impose on a system of social choice rules. His theorem states that when three or more social outcomes are feasible, it is impossible to construct a performance ordering that satisfies all five conditions:

  1) complete ordering
  2) responsiveness to individual preferences
  3) non-imposition
  4) non-dictatorship
  5) independence of irrelevant alternatives

- Because of the extremely restrictive conditions for assuring that choices are made on a consistent and comprehensive basis, the Arrow Possibility Theorem is also referred to by many as the Arrow "Impossibility" Theorem.
- The Arrow conditions are important to the results of any selection process, but we may not wish to constrain ourselves to formalized voting, scoring, and independence of evaluators. A consensus approach may serve a selection process better than formal, individual voting if the knowledge of each participant differs and may be exchanged in a beneficial way.

V. PRIVATE RATE OF RETURN BASIS FOR INVESTMENT CHOICE

Technical characteristics are not the only possible evaluation dimension for making investment choices. In the private sector the monetary requirements to carry out a project, and the expected returns, are also a basis on which to judge and rank. Such financial considerations form the basis for private sector assessments of a project's "private rate of return." Here the issue is the perceived value of the project relative to its funding requirements and risk.

A. PRIVATE SECTOR R&D PROJECT CHOICE

How to make "sound" private sector decisions on R&D investments is treated in two different ways by the literature on technological choice. One way, strategic management, is offered by such authors as Peter Drucker, Richard N. Foster, William Howard and Bruce Guile, and Joseph Marone.[1] These writers deal with the importance of the innovation process as it pertains to the overall management of competitive business enterprises and its ability to confer a competitive "edge." Business school texts and other writings also deal with these issues, including human and financing dimensions, as well as questions surrounding corporate venturing.[2] All of these works revolve around the issue of what should be considered as part of the "high-level" decision-making process for such investments.

The literature also discusses detailed approaches that may be used to evaluate and compare different technology and R&D investment possibilities. As noted almost two decades ago by author William Souder,[3] "[l]iterally hundreds of models have been

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1 Peter F. Drucker, *Innovation and Entrepreneurship: Practices and Principles*, 1985; Richard N. Foster, *Innovation, The Attackers Advantage*, 1986; William G. Howard Jr. and Bruce R. Guile, ed., *Profiting from Innovation*, 1992. Joseph Marone, *Winning in High Tech Markets*, 1993. National Academy of Engineering, *Time Horizons and Technology Investments*, 1992.

2 See, for instance: Zenas Block and Ian C. MacMillan, *Corporate Venturing: Creating New Business Within the Firm*, 1993; William D. Bygrave and Jeffry A. Timmons, *Venture Capital at the Crossroads*, 1992.

3 William E. Souder, "A System for Using R&D Project Evaluation Methods," *Research Management*, September 1978, p. 2.

developed for R&D project evaluation." Nicholas Danila, writing more recently in 1989, reported his survey results of more than "two hundred quantitative and qualitative methods for selecting R&D projects within an organization."[4] Such models include simple cost-benefit ratios, applications of linear programming, portfolio analysis techniques, group decision-making paradigms, and structured hierarchy processes.[5] It is perhaps worth noting that while no process offers anything approaching certainty, the more comprehensive techniques, particularly those that combine a variety of evaluation methods to offer composite perspectives, appear to be useful in making sure that "knowable" problems are not overlooked and that expectations are tempered.

From a microeconomist's point of view, investment choice is seen simply as an assessment of the potential magnitude of returns relative to risks incurred. That is, regardless of how risk and return are calculated, the basic "go/no-go" decision is a relatively fundamental one involving a comparison of the expected stream of returns between investments of comparable risks. *Ceteris paribus*, the economics of investments, dictates that private sector investors prefer projects that will yield the greatest returns (profits) for similar (comparable) risks. Hence, while in the world of research and development the issue of which project should receive funding is complex in

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4 Nicholas Danila, "Strategic Evaluation and Selection of R&D Projects," *R&D Management*, January 1989, p. 47.

5 For this paper we reviewed the following limited selection from this literature. William E. Souder and Tomislave Mandakovic, "R&D Project Selection Models," *Research Management*, July/August 1986. Ari P. J. Vepsalainen, "Analysis of R&D Portfolio Strategies for Contract Competition," *IEEE Transactions of Engineering Management*, August 1988. Melville H. Hodge, Jr., "Rate Your Company's Research Productivity," *Harvard Business Review*, November/December 1963. David L. Hall and Alexander Nauda, "An Interactive Approach for Selecting IR&D Projects," *IEEE Transactions of Engineering Management*, May 1990. Jeffrey L. Ringuest and Samuel B. Graves, "The Linear Project Selection Problem: An Alternative to Net Present Value," *IEEE Transactions of Engineering Management*, May 1990. Robert M. Ranftl, "Improving R&D Productivity—A Study Program and Its Applications," *Research Management*, January 1977. John G. Porter, "Post Audits—An Aid to Research Planning," *Research Management*, January 1978. Michael J. Stahl and Joseph A. Steger, "Improving R&D Productivity—Measuring Innovation and Productivity—A Peer Rating Approach," *Research Management*, January 1977. Richard N. Foster, Lawrence H. Linden, Roger L. Whiteley, and Alan M. Kantrow, "Improving the Return on R&D—I," *Research Management*, January-February 1985. Klaus Brockhoff, "A Simulation Model of R&D Budgeting," *R&D Management*, July 1985. Bela Gold, "Some Key Problems in Evaluating R&D Performance," *Journal of Engineering and Technology Management*, Volume 6, 1989. William M. Burnett, Barry G. Silverman, and Dominic J. Monetta, "R&D Project Appraisal at the Gas Research Institute: Part II," *Operations Research*, November-December 1993. Yutaka Kuwahara and Yasutsugu Takeda, "A Managerial Approach to Research and Development Cost-Effectiveness Evaluation," *IEEE Transactions of Engineering Management*, May 1990. Albert N. Link, "Methods for Evaluating the Return on R&D Investments" (mimeo).

terms of formulating the costs, benefits, and risks of alternatives, final decisions are no different from that of investing in a stock or bond.

Underlying the "simple" economics of technology investments are a whole host of issues that must be addressed to offer the quantitative comparisons useful to making business decisions. This process is best described as one which attempts to incorporate technical and institutional information in an economically meaningful way for decision makers. Figuring prominently in such assessments are questions unique to technology business decisions, as follows:

- **How easily appropriable is a technology expected to be?** A technology's appropriability is the ease with which a competing firm may acquire or replicate the researching firm's results.[6] This is a particularly important issue for private sector decision makers since it is a good indicator of how quickly competing products or processes will emerge on the market and the likely intensity of future competition. Particularly in cases where a technology investment is easily appropriated by a competitor, or worse yet easily appropriated with less research investment once the best technological options have been identified, individual investors or firms are unlikely to venture. It is also extremely important to avoid the "free rider" phenomenon, whereby non-partnership entities competitively benefit from alliance R&D without contributing to its financing. This issue also raises questions about the likelihood that foreign competitors will learn details of partnership developments and use them to feed their own projects, or that foreign governments will fund competitive commercial developments.
- **Is there a clear path to a commercial or defense market?** Clear path to market is crucial to the success of R&D activities, ensuring that technologies developed have an application in commercial or defense products or processes, and a reasonable assurance that a firm will not be out-competed. At a minimum, this involves determining the likely markets for a product or process, acceptability by customers, and the probability that financing may be secured to move technologies into marketable products or processes.
- **How should intellectual property be handled?** Intellectual property issues include the licensing and patenting of the products or processes which ultimately result from the technology investment and figure prominently when joint R&D is undertaken. In some cases, when two or more firms

6 For a particularly compelling discussion of this issue see: David J. Teece, "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy," *Readings in the Management of Innovation*, edited by Michael L. Tushmand and William L. Moore, 1988.

jointly undertake an investment, patents and licenses (including royalties) are handled within the organizational structure itself, while in other cases the results from R&D are too early in the development process for legal remedies. In other alliances members might be "free" to use results however they see fit (perhaps with some transfer restrictions), and licensing and patenting could take place on a firm-by-firm basis for final products and processes.

- **How shall "qualitative" technical risks be quantified?** Quantifying technical risks relates to the scientific or engineering merits of a project. From a business investment point of view, technical risk must somehow be expressed in monetary terms to allow a ranking of different projects and their potential rates of return. This means that the anticipated stream of returns (profits) from a new product or process should reflect the likelihood that they will be realized. In cases where risk is high, the cash flow of the project should reflect diminished expectations. In this way quantification of the returns on an investment already reflect inherent risks and the task of comparing projects is thereby simplified. (More on this, below.)
- **What are the opportunity costs of forgoing an investment?** The opportunity costs of forgoing a technology investment must also be assessed by a business. Particularly in fast-moving technology sectors the timing of research investments must be tied to the timing of new products and processes which will be marketed. The more technologically dynamic an industry, the more important the timing of product development cycles and supporting research activities. Failure to make timely investments may temporarily or permanently hamper a firm from competing effectively, or may even remove it from the market altogether.
- **Should risks be pooled or shared?** Pooling or sharing risks, a topic to which we return later, may be an attractive approach for technology investments where appropriability is high and time to market great. "Economic theory would predict that when horizontally related companies with overlapping research needs form a joint venture, efficiencies will be realized owing in large part to the reduction of duplicative research and the sharing of research results."[7] The TRP and ATP programs attest to the practical application of such principles.

In addition to considering these factors, a firm must make more traditional decisions regarding whether or not an investment will disrupt its operations, demand scarce resources, divert attention from other goals, or expose trade secrets.

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7 Albert N. Link, "Advanced Technology Program: Economic Study of the Printed Wiring Board Joint Venture After Two Years," April 1993, p. 2.

Regardless of the underlying technical, organizational, and institutional circumstances surrounding an investment, and whether or not it involves a single firm, an individual, or a consortium, in the business world the metric for measuring efficacy is a project's financial rate of return. This, in turn, reduces to an evaluation of projected profit streams and investment costs adjusted for risk. The two quantitative measures used to rank financial returns are net present value (also termed "discounted cash flow") and internal rate of return.

A project's net present value (NPV) is the sum of the stream of net benefits (net revenues or profits) generated by the project and discounted back to the present, less investment costs. If the stream of net benefits to be discounted at interest rate r is $Z(t)$ for periods $t = \emptyset$ to $t = n$, and the initial investment is I,[8] then the net present value is calculated as:

$$\text{Net Present Value} = I + Z(0) + \frac{Z(1)}{(1+r)} + \frac{Z(2)}{(1+r)^2} + \frac{Z(3)}{(1+r)^3} + \cdots + \frac{Z(n)}{(1+r)^n} \quad (5.1)$$

Project net present values are compared within the context of the overall investment budget available. For instance, assuming a $10 million initial investment, if the choice is between 10 large projects each with a $1 million NPV and 25 small projects each with an $800,000 NPV, the small projects would be the preferable investment.

An alternative to net present value is internal rate of return (IRR). This is the discount (interest) rate r which, when applied to the stream of project net returns $Z(t)$, yields a net present value equal to the initial investment I (net present value is zero):

$$\text{r such that: } I + Z(0) + \frac{Z(1)}{(1+r)} + \frac{Z(2)}{(1+r)^2} + \frac{Z(3)}{(1+r)^3} + \cdots + \frac{Z(n)}{(1+r)^n} = \emptyset \quad (5.2)$$

While internal rate of return may seem like a more direct approach to estimating the efficacy of an investment, caution must be used in calculating it because it is possible that multiple rates of return (roots) exist for a payment stream that switches between profits (positive) and losses (negative). In such a case there are as many potential internal rates of return satisfying the equation of net present value to zero as there are sign changes.

Reducing all investment decisions to simple NPV or IRR is what allows "non-financial" investment projects of all types to be compared with pure financial risks such

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8 I is a negative number.

as stocks, bonds, and commodities. This is not oversimplification, but rather the economist's way of overcoming the problems visited in Chapter IV regarding technical choice and ranking. By giving all decisions a monetary value, it becomes possible to do direct cardinal comparison for qualitatively different investments. As we have attempted to demonstrate above, it is the task of developing the monetary estimates that is non-trivial. It turns out that estimating and mitigating risk is perhaps the most thorny of issues to be faced.

B. RISK AND RISK REDUCTION

Up to this point, we have assumed that the various technical and financial characteristics of a given project are known with certainty. In reality, *uncertainty* is endemic in the development of a new product or process. It is rare indeed when the payoffs of a technical project are known *ex ante* with any degree of precision. How do we adjust the foregoing analysis to take into account uncertainty? The short answer is that the riskier the project, the higher the rate of return that is required, *if the firm/entrepreneur is risk averse and unable to diversify.*

Broadly defined, uncertainty is a probability distribution on some partition over all possible states of the world. It can include acts of both rational and irrational agents. Since describing all possible states of the world is an impossible task, in practice one must select a coarser partition. From the point of view of a profit-maximizing firm which must decide whether to undertake a project or not, it suffices to consider a partition based on the project's financial payoffs, i.e., a probability distribution over the set of monetary streams that may occur. This is the *financial risk* of a project.

In general we can divide financial risk into two categories: *technical risk* and *external risk.* Technical risk refers to uncertainty regarding the project's ability to achieve technical success, a factor over which the firm should possess some leverage. External risk refers to such market conditions as changes in prices for inputs and substitutes, the appearance of a competing product, and other things over which the firm is likely to have little if any control. This distinction may be relevant in some public policy contexts, but from the point of view of the firm, it is irrelevant if the financial risk is unchanged.

In the previous section we explored some alternative decision rules for choosing among projects. The most powerful and useful concept was that of net present value, whereby the payoff stream is discounted in each period to account for the time value of money. With uncertainty there is no longer a single stream of payoffs with which to compute NPV. One obvious approach would be to use the stream of expected payoffs. If the firm is risk neutral—or indifferent to one risk compared with another—then we are finished since a risk neutral firm is indifferent between a sure payoff and a random one with the same expected value. What happens when the firm is risk averse?

By definition a risk averse firm prefers a sure payoff to a random one with the same expected value—being risk averse means you like safe bets. In order for the firm to accept a random payoff over a sure payoff, it must be paid a *risk premium*. In other words, the project must have a *higher rate of return*. Thus in evaluating a risky project, the discount rate (r in the previous section) should be adjusted upward.

A common error is to argue that because distant payoffs are less certain, they should be discounted at a higher rate than earlier cash flows. In fact, a risk adjusted discount rate automatically accounts for the likelihood that distant payoffs are riskier. Since the factor actually used to discount any future period's cash flow is a multiple of the single period discount rate, the further out the cash flow, the greater the total risk adjustment.[9]

Does undertaking a project with a highly variable stream of payoffs mean that we should use a risk-adjusted discount rate? The answer is, not necessarily. Consider the following example.

Suppose we have an opportunity to invest in a portfolio that has a 50 percent chance of success so our payoff is either 0 or 1 for each project. We would expect the risk premium required in such a case to be quite high. However, if instead of choosing just one risky project we invest in hundreds of projects whose probabilities of success are independent of one another, we may turn uncertainty into certainty. This may be done by investing a small amount in each project and relying on the law of large numbers to force the variance of our portfolio to zero and our payoff to 0.5. Even though each project is very risky, by diversifying we eliminate virtually all of the risk. This suggests that when we decide whether to invest in the original project, we do not need to adjust for risk. Rather, we may diversify so that our payoff is constant.

Now assume that one project's chance of success is not independent of all other projects' chances. When the project results are aggregated, it is no longer possible to

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9 Paraphrased from p. 185, Brealey, R. and Myers, S., *Principles of Corporate Finance*, 2nd ed., McGraw Hill, New York, 1984.

diversify all of the risk. Nondiversifiable risk is often called "market" or "systemic" risk. It arises from economywide events that affect the success or failure of all businesses simultaneously. Such risk may be impossible to avoid diversifying and may require us to adjust the discount rate. That is, diversifying one's portfolio does not lead to a certain payoff because the factors that cause one project to fail may also affect the outcome of all others.

Some argue that with large, "bet the company" projects even risk that is not correlated to economywide factors cannot be diversified. This may well be true in some instances when the ownership of a firm is closely held. However, if the firm is publicly traded, the owners of the firm could diversify easily by selling their shares on the stock market. A prudent manager in such a firm would then ignore systemic risks in adjusting the discount rate, regardless of the size of the project.

Another way to diversify risk is through "policy"—joint project development across several firms. Such R&D alliances are a central feature of various recent government programs and may include a mixture of firms, academia, and government—their composition determined by the organizations involved. From the point of view of maximizing private rate of return, the utility of such organizational alliances is a function of the degree to which the risk of pursuing new technological opportunities may be reduced. As already discussed, such reductions may come in various forms, all of which must be distilled into a decision based on the long-term expectations of a project's rate of return if pursued individually, or collaboratively if part of a working relationship with other organizations.[10]

For any collaborative cost- and risk-sharing endeavor involving the development or marketing of commercial products or processes there is also the issue of whether or not to compete with rival firms. Particularly in the case of large firms, this involves considerations of anti-trust laws as well as potential advantages that may be conferred on a competitor as a result of collaboration, as discussed earlier. Current government-applied technology programs do not fund technology development projects beyond the stage of advanced engineering development/demonstration (final product/process development is not allowed), so anti-trust questions are generally moot. This leaves the issue of whether or not to share risk and cost during earlier stages of development, raising

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[10] For a complete overview of business alliances and their characteristics refer to: Robert Porter Lynch, *Business Alliances Guide: The Hidden Competitive Weapon*, 1993.

the appropriability and intellectual property issues discussed earlier, as well as questions of corporate "fit," distribution of revenues, market share, and so forth.

C. HOW IMPORTANT ARE "THE NUMBERS" IN SELECTING TECHNOLOGY INVESTMENTS?

To this point we have emphasized the need to reduce all investment decision making to financial quantities in order to rank the efficacy of different projects according to their anticipated returns. While this applies to technology investments, recent work by authors such as Joseph Marone demonstrates that there is much more to successful private sector technology investments than simply "relying on the numbers." The point here is that due to the extreme uncertainty regarding ultimate market size, competition, and macroeconomic forces not under the control of the firm, the quality of financial forecasts is contingent on the assumptions used in their construction—or as Marone has observed in his work, you can't just rely upon the numbers.[11]

Nevertheless, we have perceived from Marone and other writers, as well as discussions with private sector technology managers, that while financial projections are sometimes of dubious quality, they are an important exercise conducted by firms as part of the planning process. It appears that their role is not so much to pinpoint the exact size of returns from a technology investment, but rather to help assess the order of magnitude of returns that might be expected as well as to discipline the selection process to fully enunciate the assumptions upon which an investment is being promoted.

In addition to financial indicators of potential success, there is also a distinctly human dimension to the choice of technology investments—embodied experience in investment managers. This is not simply "playing hunches." Rather, in most cases successful technology investment managers use their experience and accumulated knowledge of a technology, its prospects, and the marketplace to decide upon long-range activities leading to new products and processes. Unfortunately, it is impossible to replicate the background, education, experience, and personality of highly successful managers. What this also tells us, however, is that attempts to make commercial investment decisions without a significant experience base in the target marketplace is not a robust approach.

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[11] Joseph Marone, *Winning in High Tech Markets*, p. 230.

D. SUMMARY

- Technical characteristics are not the only possible evaluation dimensions of source selection processes. In the private sector the monetary requirements to carry out a project, and the expected returns, are also a basis on which to judge and rank. Such financial considerations form the basis for private sector assessments of a project's "private rate of return." Here the issue is the perceived value of the project relative to its funding requirements and risk.
- How to make "sound" decisions on R&D investments is treated in two different ways by the literature on technological choice. One way, strategic management, deals with the importance of the innovation process as it pertains to the overall management of competitive business enterprises and its ability to confer a competitive "edge." The second way involves detailed approaches that may be used to evaluate and compare different technology and R&D investment possibilities. Such models include simple cost-benefit ratios, applications of linear programming, portfolio analysis techniques, group decision-making paradigms, and structured hierarchy processes.
- From a microeconomist's point of view, investment choice is an assessment of the potential magnitude of returns relative to risks incurred. The basic "go/no-go" decision involves comparing the expected stream of returns between investments of comparable risks.
- Underlying the "simple" economics of technology investments are a whole host of issues that must be addressed to offer the quantitative comparisons useful to making business decisions.

  1) How easily appropriable is a technology expected to be?
  2) Is there a clear path to a commercial or defense market?
  3) How should intellectual property be handled?
  4) How shall "qualitative" technical risks be quantified?
  5) What are the opportunity costs of forgoing an investment?
  6) Should risks be pooled or shared?

- In the business world the metric for measuring efficacy is a project's financial rate of return. This, in turn, reduces to an evaluation of projected profit streams and investment costs adjusted for risk. The two quantitative measures used to rank financial returns are net present value (also termed "discounted cash flow") and internal rate of return. Reducing all investment decisions to simple NPV or IRR is what allows "non-financial" investment projects of all types to be compared with pure financial risks such as stocks, bonds, and commodities.

- The various technical and financial characteristics of a given project are not known with certainty. In reality uncertainty is endemic in the development of a new product or process. It is rare indeed when the payoffs of a technical project are known *ex ante* with any degree of precision.

- From the point of view of a profit-maximizing firm that must decide whether to undertake a project or not, it suffices to consider a partition based on the project's financial payoffs. This is the *financial risk* of a project. In general we can divide financial risk into two categories: *technical risk* and *external risk.* Technical risk refers to uncertainty regarding the project's ability to achieve technical success, over which the firm should possess some leverage. External risk refers to such market conditions as changes in prices for inputs and substitutes, the appearance of a competing product, and other things over which the firm is likely to have little if any control.

- In addition to financial indicators of potential success, there is a distinctly human dimension to the choice of technology investments—embodied experience in investment managers. Successful technology investment managers use their experience and accumulated knowledge of a technology, its prospects, and the marketplace to decide on long-range activities leading to new products and processes. Unfortunately, it is impossible to replicate the background, education, experience, and personality of highly successful managers.

VI. SOCIAL RATE OF RETURN BASIS FOR INVESTMENT CHOICE

When the private sector is not interested in undertaking a project because its "appropriable" rate of return is unattractive or it does not have proper corporate fit, it does not necessarily mean that the project is unattractive to society at large. The *net* importance of an investment for society as a whole, taking into account all benefits and costs, may be disproportionately larger or smaller than for private individuals. A literature has grown up around this issue.

Two approaches are in general use to *retrospectively* assess the relative significance of a project for society: 1) econometric studies deal with improvements in productivity and output achieved that result from a particular technological change; and, 2) social net surplus studies calculate overall net benefits including consumer savings and job formation/loss (this work is associated with Edwin Mansfield).[1] Either could be of interest within the context of dual-use technology promotion and CMI. Both types of studies have strengths and weaknesses. Neither produces results that provide a good basis for forecasting the future economic impacts of technological changes, as will become evident below.

This chapter reviews the current understanding of the social returns from technological change. Given the extent and complexity of the literature, we intend only to represent the types of results from research to date.

A. ECONOMETRIC EVIDENCE OF THE ECONOMIC IMPACTS OF TECHNOLOGICAL CHANGES

As a rule, econometric studies of the impacts of technological change observe and quantify apparent statistical relationships between a dependent variable, such as output, profitability, or productivity, and a set of independent variables which usually measure labor, skills, "technology," and capital stock. On occasion, however, such studies have

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1 Firm-specific assessments may also be undertaken using econometric methods, although for reasons to be discussed below there are advantages to Mansfield's method that tend to obviate their results.

also used independent variables that generally fall outside the actual production process, such as bibliometric and patent data, although the results here have been far less than encouraging.[2]

At the outset it is important to distinguish the use of econometric assessments for the purposes of testing hypotheses retrospectively, and the use of econometric results for forecasting economic performance. This is particularly the case when dealing with technological change for the following reasons.

Econometrics is the quantification of stochastic relationships based on observations that are purported to be evidence supporting or refuting an economic proposition. The usual tests of robustness for such propositions are statistical measures indicating the "goodness of fit" of data based upon equations structured according to the proposition to be tested. Such measures include assessments of variance and potential statistical anomalies (e.g., auto-correlation, heteroskedasticity, multi-colinearity, and simultaneous equation bias) which may interfere with the testing of hypotheses.

Because econometric assessments necessarily rely on historical observations, and technological changes generally lead to "discontinuities" or modifications in the relationships between factors upon which such observations are based, forecasting the impact of technological changes using historical relationships is generally not possible. Take the oversimplified hypothetical example given in Figure VI-1, where an "old" technology is replaced by a "new" one. In this case an econometric forecast based on the characteristics of the old technology yields a projection which fails to reflect the overall greater capabilities of the new one. In particular, the new technology cost/performance curve is on a path above the old curve and has a greater slope.

While the example in Figure VI-1 is admittedly simplistic, it does illustrate the dangers of extrapolating based on historical data. In fact, practical examples of such difficulties exist. For instance, some economists predicted long-term dire shortages of petroleum and other hydrocarbon resources as a result of oil embargoes in the mid and late 1970s. Unfortunately, such projections did not take into account the rapid technological changes that were spurred by price increases and concomitant shifts in consumer preferences toward energy efficient vehicles, dwellings, and business practices. While

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2 See especially: Zvi Griliches, "Productivity, R&D, and the Data Constraint," *American Economic Review*, March 1994.

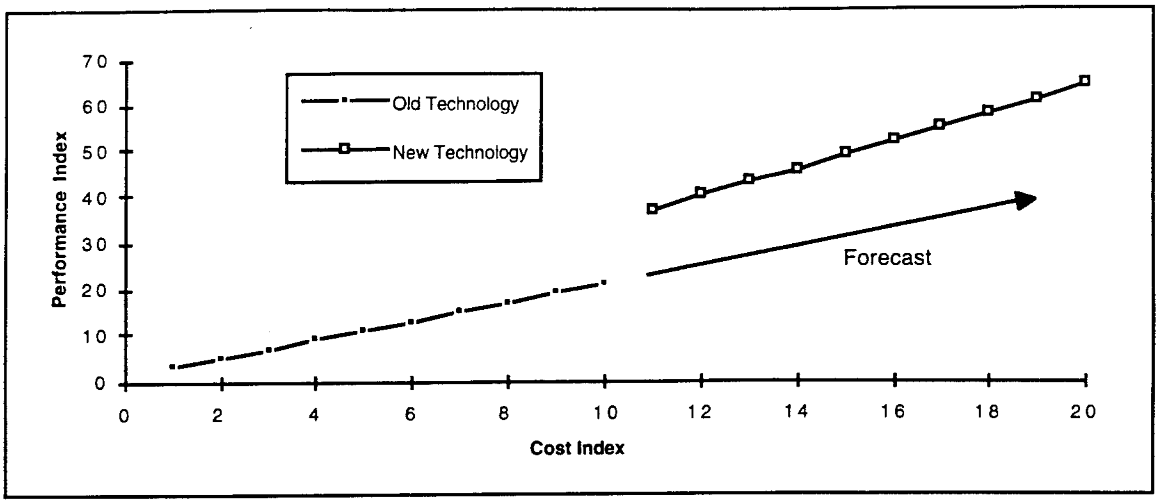

Figure VI-1. Hypothetical Econometric Forecast of Cost and Performance for a New Technology

the embargoes did result in considerable short-term dislocations, in the long-term the economy adapted to the new supply-demand realities and the predicted shortages never occurred.

Thus, we must view econometric and other approaches to estimating the impacts of "progress" as quantitative indicators of the importance of technological change to economic growth and productivity. If we believe that "the past is prologue," such evidence may be used to structure public policies to take advantage of the potential benefits from technological progress, but in no way does it give us a deterministic tool for choosing investments or projecting their impacts.

Explaining the role of technological change on an aggregate, economywide or industry sector basis is particularly important for the economics profession in its attempt to understand the significance of various types of macroeconomic and sector-specific policies. The difficulty in conducting such assessments is in distinguishing changes in economic productivity and output that are attributable to technical progress from those changes that result simply from growth in the amount of capital used in the production process or the quality and size of the work force.

Economists have employed a variety of measures to determine the extent to which changes in the capital stock and underlying technologies affect productivity, but two are generally in use. One, labor productivity, is simply output divided by labor hours; the other, multi-factor productivity, involves statistical regression of output over time as a dependent variable against different categories of inputs (usually capital, labor, and intermediate goods) as independent variables.[3]

Productivity improvements, themselves, form the basis for growth in per capita national welfare since they allow increased levels of output to be produced with fewer resources. Increasing labor productivity means that less employee time is required to produce the same level of output. Increasing multi-factor productivity more generally measures the reduction in different types of resources, including labor, necessary in a given span of time to produce a level of output.

Although productivity measures are important guide posts for understanding the effects of economic changes resulting from new technologies, they are not particularly useful in isolating and identifying the results from a specific project or investment. Indeed, while quantitative measures are possible to obtain, they do not allow us to derive a net social impact from the change; such net assessments are the real goal for determining the efficacy of a particular technology investment.

For instance, labor productivity would rise without technological change if production processes adopted already-available technologies that automate operations and raise the level of output per worker. It is possible to argue that this is in fact a technological change, but since it comes as an increase in a constant-technology capital stock it is not generally treated as such. Similarly, it is also possible to argue that the manner in which labor is organized in the production process could be changed and reflected as increased labor productivity and output. Again, this is treated as a return to labor and management, and not technology. The impact of education on economic variables is similarly difficult to assess.[4]

The quantitative study of the importance of technological change to the national economy as a whole has its roots in work performed by Robert Solow in 1956 and 1957.[5] In this work and subsequent analyses by others the central issue has been that just

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3 For a complete and accessible discussion of the productivity issue see William J. Baumol, Sue Anne Batey Blackman, and Edward N. Wolff, *Productivity and American Leadership*, Cambridge, Mass., 1989.

4 This is included as an issue in technology transfer discussions as well. See: Edwin Mansfield, Anthony Romeo, Mark Schwartz, David Tecce, Samuel Wagner, and Peter Brach. *Technology Transfer, Productivity, and Economic Policy*, 1982, pp. 9–10.

5 Robert M. Solow, "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics* 70, 1956, pp. 65-94. Robert M. Solow, "Technical Change and the Aggregated Production Function," *Review of Economics and Statistics* 39, 1957, pp. 312–320.

described, how to distinguish the contribution to productivity and growth made by technological change from the contribution of an expanding capital stock and a more capable labor force. Some assessments have dealt with technological change as an exogenous "residual" in econometric expressions, while others have attempted to deal with the efficacy of R&D as an endogenous variable.

For instance, recent work in this area by Boskin and Lau offers strong evidence that the contribution of technological change to economic growth across five different national economies is "by far the most important source of economic growth of the industrialized countries in [their] sample." They also conclude that "the benefits of technical progress are higher the higher the level of capital stock."[6] The analytical method for their results is an econometric analysis that attempts to separate the different factors contributing to economic growth and productivity, but ultimately technological change is still regarded as an unexplained residual in their equations. (See Appendix A for their summary of previous authors' results.)

Such aggregate national or international assessments do not address critical questions regarding the importance of technological change for different industries within the economy or for innovating firms. From a public policy standpoint this too is important, particularly when the goal is to influence the economic performance of an industry or sector that is performing "poorly" in some sense (low growth, or perhaps lagging in productivity compared with its foreign counterparts).

While aggregate theories of technological change appear to uphold the premise that innovation is important to economic progress, they are hobbled by their generality as explanations of the nature and importance of innovation within an industry. To address issues at this level a variety of studies have attempted to assess the relative importance of research and development investments and technological change for individual industries or groups of industries. Work has also been recently extended by attempts to quantify the contribution of academic R&D on the performance of various industries.[7]

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6 The countries in the study were France, Germany, Japan, the United Kingdom, and the United States. Michael J. Boskin and Lawrence J. Lau, "Capital, Technology, and Economic Growth," *Technology and the Wealth of Nations*, edited by Nathan Rosenberg, Ralph Landau, and David C. Mowery, 1992, p. 50.

7 At the industry or sector level of assessment investigators also face the problem of adequately separating impacts due to technological change from other factors. To the extent that this is done, any contribution to growth or productivity still cannot be attributed to one or another particular technological change, and management factors remain a significant question.

One portion of this literature has concentrated on returns to agriculture. Examples include the works of Griliches, Peterson, and Evanson, Wagoner, and Ruttan.[8] In general, these studies provide evidence that significant productivity gains have been obtained through agricultural research and application of its results. The other portion of the literature has been concerned with assessing the importance of research to industry. Examples of such work include those of Minasian, Mansfield, Scherer, Link, and Bernstein and Nadiri.[9] Again, results tend to confirm that investments in research and development offer significant rates of return to productivity. Attempts to assess the economic benefits from academic R&D also offer evidence of high rates of return to industries. Although this literature is extremely limited, Jaffe, Mansfield, and others[10] have concluded that the impact of academic R&D on productivity and industrial rates of return has been "substantial."

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8 Zvi Griliches, "Research Expenditures, Education, and the Aggregate Agricultural Production Function," *The American Economic Review*, December 1964. Zvi Griliches, "Productivity, R&D, and Basic Research at the Firm Level in the 1970's," *The American Economic Review*, March 1986. Willis L. Peterson, "Return to Poultry Research in the United States," *Journal of Farm Economics*, Volume 49, 1967. Robert E. Evanson, Paul E. Waggoner, and Vernon W. Ruttan, "Economic Benefits from Research: An Example from Agriculture," *Science*, September 14, 1979. Willis L. Peterson, "Returns to Investment in Agricultural Research in the United States," April 1969.

9 Edwin Mansfield, "Technological Changes: Stimuli, Constraints, Returns. Rates of Return from Industrial Research and Development," *American Economic Review*, 55, 1965. Edwin Mansfield, "Basic Research and Productivity Increase in Manufacturing," *American Economic Review*, December 1980. Jora R. Minasian, "Research and Development, Production Functions, and Rates of Return," *American Economic Review*, Volume 59, 1969. F. M. Scherer, "Inter-Industry Technology Flows and Productivity Growth," *Review of Economics and Statistics*, Volume 64, 1982. Albert N. Link, "Basic Research and Productivity Increase in Manufacturing: Additional Evidence," *American Economic Review*, December 1981. Jeffrey I. Bernstein and M. Ishaq Nadiri, "Interindustry R&D Spillovers, Rates of Return, and Production in High-Tech Industries," *AEA Papers and Proceedings*, May 1988. Most recently the Economics and Statistics Administration has begun to employ its Longitudinal Research Database to confirm the importance of technology to productivity and employment. Department of Commerce, *Technology, Economic Growth and Employment: New Research from the Department of Commerce*, December 1994.

10 Adam B. Jaffe, "Real Effects of Academic Research," *American Economic Review*, December 1989. Edwin Mansfield, "Academic Research and Industrial Innovation," *Research Policy*, February 1991. James D. Adams, "Fundamental Stocks of Knowledge and Productivity Growth," *Journal of Political Economy*, Volume 96, 1990. Donald N. Steinnes, "Research and Practice: On Understanding and Evaluating the University's Evolving Economic Development Policy," *Economic Development Quarterly*, Volume 1, 1987. Koya Azumi and Frank Hull, "Inventive Payoff from R&D in Japanese Industry: Convergence with the West?," *IEEE Transactions on Engineering Management*, February 1990. CBO Staff Memorandum, "A Review of Edwin Mansfield's Estimate of the Rate of Return from Academic Research and Its Relevance to the Federal Budget Process," April 1993. There have also been periodic reviews of the NSF Engineering Research Centers, beginning with: National Science Foundation (by National Research Council), *Evaluation of the Engineering Research Centers*, November 1986.

In addition to studies of industry and university contributions to growth and productivity via technology investments, there is an incipient literature on the impact of economic outreach activities targeting small and medium-sized firms with technology assimilation and management assistance, such as NIST's Manufacturing Extension Partnerships Program, as well as on applied technology endeavors such as NIST's Advanced Technology Program. While available writings report favorable initial outcomes from these investments, only time and retrospective assessments will reveal whether and to what extent they led directly to the improvement of firms assisted and benefited the private sector.[11]

B. SOCIAL NET SURPLUS STUDIES

At the level of the firm, a host of studies have been sponsored to assess the private and social rates of return for particular innovations. Econometric techniques may be used for such assessments, but another approach that is similar to cost-benefit analysis became popular in the mid-1970s. This approach, which is generally credited to Mansfield but is rooted in studies by Griliches, uses net social surplus techniques to assess changes in social welfare based upon relatively simple notions of economic surplus. The general approach is to calculate the gross gains to producers and consumers from an innovation, subtract any gross losses, and then assess and quantify negative or positive market reactions, including labor markets.

In particular, Mansfield assesses the benefits and costs from technological innovation as reflected primarily in changes in costs, prices, and sales. The advantage of this over econometric methods is that it explicitly attempts to assess gains to society that do not show up as profit on investment. Mansfield's original work on assessing such net

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[11] See, for instance: Albert N. Link, *An Evaluation Plan for Measuring the Economic Impact of the Advanced Technology Program*, May 1992. Richard L. Chapman, Marilyn J. Chapman, Mary F. Chapman, and Jody Briles, *The Nature and Extent of Benefits Reported in NASA Spinoff*, September 1993. Gregory Tassey, "The Economic Roles and Impacts of NIST's Laboratory Research in Support of U.S. Industry" (mimeo). Philip Shapira, Jan Youtie, and David Roessner, *Review of Literature Related to the Evaluation of Industrial Modernization Programs*, June 1993. Ruth Haines, *Project Reporting and Evaluation: NIST Manufacturing Extension Partnership*, December 1993. John Baron, "A Breakthrough in Technology Transfer," *Economic Development*, Fall 1992. Roger S. Ahlbrandt, "Helping Small Manufacturing Companies Become More Competitive: A Model and Evaluation," *Economic Development*, Winter 1992. Johnathon Baron, "Linking Companies with Outside Technology: An Effective New Approach," *Technovation*, Volume 5, 1992. Philip Shapira, "Modern Times: Learning from State Initiatives in Industrial Extension and Technology Transfer," *Economic Development Quarterly*, August 1990. Irwin Feller, "Evaluating State Advanced Technology Programs," *Evaluation Review*, June 1988.

social benefits from technological changes was published in 1975 under a grant from the National Science Foundation (NSF).[12] Subsequently, two contracts were let by NSF, one to Robert Nathan and Associates and the other to Foster Associates; both published results in 1978.[13] All three efforts provide evidence that there are substantial returns on R&D investments, and that social returns tend to far exceed private returns from such investments. (Appendix B reproduces the findings of these three studies.) This upholds the more aggregate studies mentioned above, but also leads to the conclusion that the public sector underinvests in R&D.

Since firm-level assessments are directly relevant to the assessment of non-military (economic) benefits from CMI, Mansfield's approach will be discussed in some detail in the following sections. The approach involves five basic steps:

1. Calculate the size of consumer's and producer's surpluses
2. Calculate the change in these surpluses due to technological changes
3. Estimate and include labor market impacts
4. Estimate and include externalities
5. Combine (b) through (d) and calculate IRR and NPV

1. Calculation of Consumer's and Producer's Surpluses

The consumer's and producer's surpluses are practical measures of the overall benefits accruing to producers and consumers from market interactions. In a competitive market, such as that shown in Figure VI-2(a) with a downward sloping demand curve *d* and upward sloping supply curve *s*, these surpluses are shown as areas above and below the "price" line, *p*.

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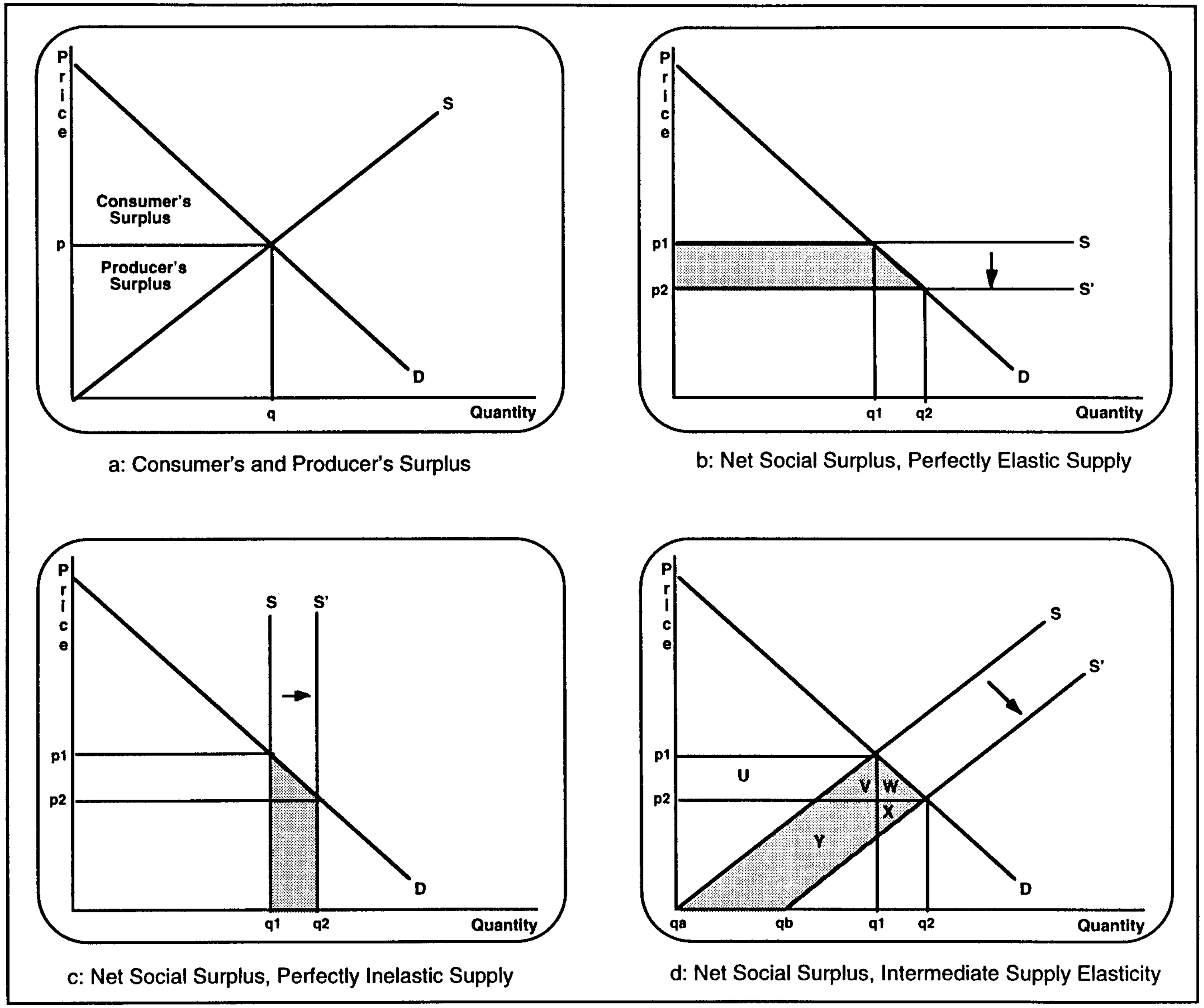
[12] National Science Foundation, *Social and Private Rates of Return From Industrial Innovations* (2 volumes), 1975.

[13] For a summary of Mansfield's results see: Edwin Mansfield, "Social and Private Rates of Return from Industrial Innovations," *Quarterly Journal of Economics*, May 1977. Also see: National Science Foundation (Foster Associates, Inc.), *A Survey of Net Rates of Return on Innovation* (3 Volumes), May 1978. National Science Foundation (Robert R. Nathan Associates, Inc.), *Net Rates of Return on Innovations* (3 Volumes), October 1978. Other efforts include: J. G. Tewksbury, M. S. Crandall, and W. E. Crane, "Measuring the Societal Benefits of Innovation," *Science*, August 1980. A recent summary of findings and limitations may be found in: Edwin Mansfield, "Social Returns from R&D: Findings, Methods, and Limitations," *AAAS Science and Technology Policy Yearbook 1991*.



a: Consumer's and Producer's Surplus

b: Net Social Surplus, Perfectly Elastic Supply

c: Net Social Surplus, Perfectly Inelastic Supply

d: Net Social Surplus, Intermediate Supply Elasticity

Figure VI-2. Mansfield Social Surplus Calculations

A consumer's surplus exists in Figure VI-2(a) because increasingly higher levels of demand lead to lower prices for all consumers. Hence, even consumers willing to pay $p^*>p$ pay only p. The difference between p and p^* is a savings to consumers. The aggregate of all such savings is the area below the demand curve d and above the price line p.

A producer's surplus exists in Figure VI-2(a) because increasingly higher levels of demand lead to greater levels of output (it may be thought of as the profit on enterprise). The figure shows, however, that each incremental unit of output costs more than the previous unit, until the cost of production exactly equals the price level. Hence, producers accrue a surplus which equals the area above the supply curve s and below the price line p.

2. Measurement of Changes in Consumer's and Producer's Surpluses Resulting From New Technologies

New technologies that lead to changes in the costs of production may affect the shape and position of the supply curve. When this happens, the point of demand-supply intersection, which yields a price-quantity relationship in the marketplace that is in equilibrium, is also affected. Figures VI-2(b), (c), and (d) offer hypothetical examples of the impact of a technological change that shifts the supply curve from s to s', causing equilibrium price and quantity to shift from point ($p1$,$q1$) to point ($p2$,q2). How does this affect net social surplus? This depends largely on the shape of the supply curve.[14]

Beginning with Figure VI-2(b), which depicts a perfectly elastic (horizontal) supply curve, the net gain in social surplus is represented by the shaded area bounded by the two supply curves and the demand curve. Because the supply curve is horizontal, there is only a gain to consumer's surplus since there is no area below the price line and above the supply curve. Hence, the net gain in social surplus is coincident with the net gain in consumer's surplus. This area is calculated as:

$$(p1-p2)q1+\int_{q1}^{q2} f_d(p)dq-(q2-q1)p2, \qquad (6.1)$$

[14] See, for instance: Andrew Schmitz and David Seckler, "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester," *American Journal of Farm Economics* 52, 1970, pp. 570-571.

where $f_d(p)$ is the functional form of the demand curve. If the demand curve is linear this reduces to:

$$(p1 - p2)q1 + (q2 - q1)(p1 - p2)/2. \qquad (6.2)$$

When data are scarce, estimates of the demand and supply curves are not possible and Eq. (6.2) is used as a convenient simplification, although it may under- or over-estimate the size of the net change in social surplus.

Figure VI-2(c) depicts a perfectly inelastic (vertical) supply curve. Again, the net gain in social surplus is represented by the shaded area bounded by the two supply curves and the demand curve. Note that there is a larger gain in the producer's surplus than in the consumer's surplus. This area is calculated as:

$$\int_{q1}^{q2} f_d(p)dq. \qquad (6.3)$$

If the demand curve is linear this reduces to:

$$(q2 - q1)p2 + (q2 - q1)(p1 - p2)/2. \qquad (6.4)$$

Finally, Figure VI-2(d) illustrates the net change in social surplus when the supply has an intermediate elasticity (is positively sloped but neither horizontal nor vertical). The new position of the supply curve affects both the producer's and consumer's surplus in the following way. Consumers gain the area $(U + V + W)$, while producers gain $(X + Y)$ and lose U. Hence, the net social welfare gain is $(U + V + W) + (X + Y) - U$, or $(V + W + X + Y)$. This net gain is again the (shaded) area between the supply curves and below the demand curve. Its calculation, which is not straightforward, would be:

$$\int_{qa}^{q1} f_s(p)dq - \int_{qb}^{q1} f_{s'}(p)dq + \int_{q1}^{q2} f_d(p)dq - \int_{q1}^{q2} f_{s'}(p)dq, \qquad (6.5)$$

where $f_s(p)$ and $f_{s'}(p)$ are the functional forms of the supply curves s and s', respectively, and $\varnothing \le qa \le qb \le q1 \le q2$.

The practical estimation of the consumer's and producer's surpluses has been undertaken by conducting case studies of technological innovations that have had demonstrable impacts on market prices and demands. Researchers collect information on a before and after basis for the case, estimate the shape of the demand and supply curves where possible, and then calculate the net social surplus as just discussed. Such an approach has the obvious limitation that it focuses only on success stories and tells us virtually nothing about research which is uncommercialized (although the R&D costs of uncommercialized research are factored into the assessments).[15]

Other problems with using the consumer's and producer's surpluses in making net impact estimates arise from the quality of data available for use in estimation procedures, its accuracy, and definitional consistency. For instance, the shapes of demand and supply curves are not always obvious or even calculable leading, as noted, to under- or overestimation of overall impacts.[16] Another problem is that the original Mansfield approach assumes that only small price changes are involved, although techniques for making estimates in the presence of large price shifts are available.

3. Labor Market Impacts

In addition to changes in the consumer's and producer's surpluses that arise from technological innovation, there are related labor market effects which must be taken into account. Generally, most innovations reduce labor requirements, and possibly result in job loss and increased unemployment, but this is not always the case. For instance, in a growing industry innovation may lead to lower producer costs, which would translate into lower prices. If demand is sufficiently elastic—that is, the percent increase in demand rises proportionately much faster than the percent decline in price—it is possible that employment could increase industrywide. But, even if job loss did occur, this effect could possibly be shifted to competitors in foreign locations if the innovation significantly improved the U.S. firm or industry's market share.

Measuring the social welfare implications of labor market impacts is not a straightforward exercise. While the level of wages and employment in an industry or firm is recorded, the displacement of workers and their reentry into the job market has potentially ambiguous effects on society. For instance, job loss may depress the overall

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[15] This point is controversial. Mansfield takes uncommercialized research and development costs and adds these to the costs of commercialized products/processes to arrive at a complete R&D investment calculation. This has perhaps been unjustly criticized by a 1978 NSF Study which states: "[T]he Mansfield method assigns all of the cost of uncommercialized R&D to new commercialized innovations. This is not typical commercial practice. Typical practice is to assign the cost of uncommercialized R&D to either a related product line, which usually includes established products, or to assign cost to general overhead of the company, which in effect prorates it over all established new products." National Science Foundation, *A Survey on Net Rates of Return to Innovations*, Volume 2, May 1978, pp. 20–24.

[16] It has been suggested that a vertical and horizontal supply curve may alternatively be assumed to derive boundary estimates for social surplus calculations. See, for instance, Schmitz and Seckler, *Mechanized Agriculture and Social Welfare*, pp. 570–571.

level of wages for particular skills in one or more industries. This could lead to lower prices for the products from these industries, but this does unemployed workers little good. Conversely, in a growing economy the reabsorption of labor into the workplace may occur quickly, with the potential that workers could find better employment than they previously had. Hence, the duration of unemployment caused by technological changes is an important issue.[17]

Mansfield's 1975 study, for instance, indicates little "evidence of an appreciable change" in unemployment resulting from an innovation. "[A]lthough labor requirements sometimes were reduced by the innovation, growth in output offset these reductions."[18] This work goes on to address the additional questions of capturing the effect an innovation in one industry may have upon products or processes in other industries. Such impacts could include the displacement of supplementary products or processes, price effects, and changes in employment in related sectors.

4. Externalities

The final consideration in estimating changes in net social welfare is the effect that a technology will have on factors not accounted for by the marketplace or measured easily with prices. Such effects are termed "externalities" by economists, and they include such harmful consequences as pollution, crime, and stress, and such beneficial consequences as faster transportation, improved educational opportunities, and better health. Externalities fall outside of the marketplace in the sense that they confer a good or bad that is not reflected in the price of a product or process.

For instance, for years water pollution from industrial firms was unregulated. Contaminated rivers and streams meant a reduction in their recreational value and increased costs for water purification. Prior to regulation, none of this was reflected in the price of the polluter's goods. Conversely, the construction of the national highway system led to improved transportation and greatly encouraged the use of motor vehicles. This benefit has been captured by highway users, vehicle producers, and others.

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17 Schmitz and Seckler, for instance, note that it is important to understand the rate of new technology adoption when estimating the impact on the labor force. "Mechanized Agriculture and Social Welfare," p. 572.

18 Edwin Mansfield et al., "Social and Private Rates of Return from Industrial Innovations," *Quarterly Journal of Economics*, May 1977, p. 238.

Historically, it has been problematic to incorporate external effects into assessments of social welfare because of such knotty issues as the quality and value of human life, the competing interests of different groups (e.g., environmentalists versus industrialists), concerns for historical and cultural preservation, and so forth. Such effects influence the impacts of new technologies because they have the potential to revolutionize our daily lives, environment, and social relationships.

Recently, attempts have been made to assess the value of natural resources, such as parks, and the impact of man-made disasters, such as the Exxon Valdez accident in Alaska. Some researchers have conducted surveys in which they asked respondents to place a price on the resource or happenstance. As noted by some economists, such approaches are likely to lead to gross over- or underestimation because survey respondents are being asked for a subjective valuation without bounds. In essence, their response is not disciplined by an actual trade-off whereby they are required to sacrifice or pay out of pocket their valuation to redress the issue. Hence, results are not only ambiguous but unreliable.

It is beyond the scope of this paper to enter into discussions regarding the quantification and qualification of social tradeoffs as it is treated in the economics literature. However, it should be noted that this literature is extensive and to some degree contentious, offering a variety of different approaches to operationalizing economic theories on the subject.

5. Calculation of NPV and IRR

The final step in calculating Mansfield's social rate of return is to create a stream of costs and benefits accruing to consumers and producers over time, including estimates of labor market impacts and externalities, and to subject these to an NPV and an IRR calculation. Note that without the consumer's surplus, labor market, or externality considerations, this reduces to the simple calculation of private rate of return. The difference is the net benefit to society beyond privately appropriable returns.

In virtually all of the net social surplus estimates made over the years this rate of return tends to be significantly larger than the privately appropriable return for investments.[19] This has led the economics profession to conclude that generally society

[19] See Appendix A, where we have reproduced the results of the original NSF-sponsored social rate of return studies.

underinvests in technology. Note that this social rate of return *is* adjusted for "bad" investments that never reach commercialization.

C. OBSERVATIONS ON THE LIMITATIONS TO SOCIAL CHOICE

This chapter has focused on the limitations of procedures for estimating the social and economic impacts of technology investments. For almost 40 years researchers have assessed the relationships between innovative activity and the economy, but still there is no comprehensive, workable economic theory for *ex ante* estimating the precise impacts of technological change on the economy as a means of focusing R&D investments. Available empirical evidence, deduction, and inference do, however, suggest strong linkages. But, as Edwin Mansfield observes, "these studies can provide very limited guidance" and because they are "retrospective, they shed little light on current resource allocation decisions, since decisions depend upon the benefits and costs of proposed projects, not those completed in the past." Zvi Griliches offers similar sentiments when he opines that "[i]t is unlikely that we can have a fully 'endogenous' theory of technological change" because "the outcome of inventive activity is not really predictable."[20]

Our knowledge regarding the relationship between innovation and economic performance is necessarily limited by the indistinctness of a set of phenomena that we lump together under the rubric of "technological change." All at once we must attempt to quantify the magnitude of technological change on a physical and financial basis, catalog the qualitative transformations involved, and then map this into the "human/social" dimension in order to apply know-how for commercial or other purposes. Our interpretation of the benefits and costs from technological change are therefore extremely context-sensitive since qualitative factors lead to clear abstract principles but muddled details.

The issue, then, is how to attribute impacts to specific technological changes when, for instance, changes occur concurrently or completely new products or processes emerge that do not have predecessors with which they can be compared. Similarly, technologies embedded in complex products present the problem of assessing the contribution of the technology vis-á-vis the complete product or process. Should its contribution be apportioned to its portion of overall cost? Are there market considerations such as monopoly, oligopoly, licensing, or patent rights that must be

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20 Edwin Mansfield, "Social Returns From R&D: Findings, Methods and Limitations," *AAAS Science and Technology Policy Yearbook*, 1991, p. 26. Zvi Griliches, "Productivity, R&D, and the Data Constraint," *American Economic Review*, March 1994, p. 18.

considered? For new products or processes, on what basis do we measure savings or changes in social surplus?

Such issues have not gone unnoticed by the economics community. The 1978 Nathan and Associates study of 20 innovations acknowledges such measurement issues, but goes even further to question whether a truly representative sample of innovations may ever be assembled.[21] As for using retrospective assessments for predicting where to invest in the future, Mansfield and Griliches reinforce our assertion that studies of technological change to date offer little assistance in making such decisions.

The foregoing analysis also demonstrates that attempts at *precise projections* are likely to be inaccurate at best and misleading at worst. Conversely, there is a need to attempt to validate the economic impacts of technology investments, particularly when they are touted as having commercial potential as part of their social benefits. This means when the marketplace is explicitly targeted, such as for dual-use investments, the strategic framework employed for selecting opportunities should at a minimum involve an assessment of the size, historical growth, and employment in industry sectors that would be affected by positive investment outcomes. Attempts to quantify the economic impacts from technology investments may then be undertaken to offer a cardinal ranking of technological opportunities according to their private and social rates of return.

Thorough examination and ranking of market opportunities is not sufficient, however, to justify any one investment or a series of investments. In addition, an understanding of how firms will behave when availing themselves of public monies is important. Since CMI is the ultimate goal of dual-use investments, this understanding must also include principles that explain how such behavior may be modified through public expenditures to achieve industrial integration.

D. SUMMARY

- When the private sector is not interested in undertaking a project because its "appropriable" rate of return is unattractive or it does not have proper corporate fit, it does not necessarily mean that the project is unattractive to society at large. The *net* importance of an investment for society as a whole, taking into account all benefits and costs, may be disproportionately larger or smaller than for private individuals.

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21 National Science Foundation (Nathan and Associates), *Net Rates of Return*, 1978, pp. 39–41.

- Two approaches are in general use to *retrospectively* assess the relative significance of a project for society: 1) econometric studies deal with improvements in productivity and output achieved because of a particular technological change; and, 2) social net surplus studies calculate overall net benefits including consumer savings and job formation/loss (this work is associated with Mansfield).
- Econometrics is the quantification of stochastic relationships based on observations that are purported to be evidence supporting or refuting an economic proposition. At best we can take econometric and other approaches to estimating the impacts from "progress" as quantified bodies of evidence of the importance of technological change to economic growth and productivity. If we believe that "the past is prologue," then such evidence may be used to structure public policies to take advantage of the potential benefits from technological progress, but it does not give us a deterministic tool for choosing investments or projecting their impacts.
- Recent econometric work by Boskin and Lau on returns to productivity from technology offers strong evidence that the contribution of technological change to economic growth across five different national economies is "by far the most important source of economic growth of the industrialized countries." They also conclude that "the benefits of technical progress are higher the higher the level of capital stock."
- At the level of the firm, a host of studies have been sponsored to assess the private and social rates of return for particular innovations. Econometric techniques may be used for such assessments, but another approach that is similar to cost-benefit analysis became popular in the mid-1970s. This approach, which is generally credited to Mansfield but is rooted in studies by Griliches, uses net social surplus techniques to assess changes in social welfare based upon relatively simple notions of economic surplus.
- Net social surplus studies involve five basic steps:
    1. Calculate the size of consumer's and producer's surpluses
    2. Calculate the change in these surpluses due to technological changes
    3. Estimate and include labor market impacts
    4. Estimate and include externalities
    5. Combine (2) through (4) and calculate IRR and NPV
- Despite the significant amount of analysis of the economics of technological change, to date there is still no comprehensive, workable economic theory for *ex ante* estimating the precise impacts of technological change on the

economy as a means of focusing R&D investments. Available empirical evidence, deduction, and inference do, however, suggest strong linkages.

PART 3

CONCLUSIONS AND RECOMMENDATIONS

VII. PURSUING A LONG-TERM COMMERCIAL-MILITARY INTEGRATION STRATEGY THROUGH DUAL-USE INVESTMENTS: CONCLUSIONS AND RECOMMENDATIONS

Throughout this paper we have summarized our observations at the end of each chapter. Now we stand back from these details to understand the bigger picture and formulate conclusions and recommendations.

CONCLUSION: **Commercial-Military Integration (CMI) is a natural and logical outgrowth of the rapidly increasing capabilities of private sector, commercial technologies worldwide.**

The assertion that defense production is becoming inseparable from the commercial industrial and technology base—the commercial economy—should come as no surprise. It has been difficult, however, to address the national security implications of diminishing U.S. economic prowess relative to other industrialized nations within the U.S. security policy framework of the past several decades. During the post-World War II period, the national strategy focused primarily on military security; in contrast, our allies concentrated on rebuilding their war-devastated economies. It is a testament to the vast economic and technological head-start the United States had after the War that for 30 years it remained the undisputed world leader both militarily and economically.

In Part 1 of this paper we argued that in recent years many military-unique technologies have emerged, leading some to conclude that the relevance of commercial technologies to the military are in the process of disappearing. However, this conclusion is inconsistent with recent policies that seek to maximize declining defense budgets through affordable weapon systems that make use of commercial-sector capabilities. According to these policies, in the same way that we moved from spin-off to militarily unique systems in the Cold War, we will move from militarily unique to spin-on systems now by promoting an integration of the military and commercial industry bases (CMI). Understanding what types of dual-use technology investments will lead to successful industrial base integration, and which are militarily attractive but not commercially viable, is key to formulating a DoD dual-use investment strategy. In fact, there will always be an important need for some military-specific technology development for state-of-the-art weapon systems and associated production techniques.

CONCLUSION: **Achieving CMI will require significant effort on the part of the Department of Defense to bring its procurement and acquisition systems "business practices" into line with commercial norms. The role of dual-use investments in this context is to demonstrate the potential benefits for both commercial and defense firms who choose to serve both sectors.**

Especially in this era of declining defense budgets we must recognize that the current breadth of military technological advance cannot be sustained "solely" by a significantly smaller defense industry, and commercial industry must come to form the basis for force reconstitution and serve as a major source for new technological knowledge. But in order to receive more militarily useful technologies from commercial industry, the needs of the defense community must somehow become aligned with commercial production goals. Attending this process is the issue of the appropriate role of the public sector in making the best use of industry for national security purposes in the absence of the immediate purchase of weapon systems. This is fraught with all of the issues of the industrial/technology policy debate, particularly difficulties in distinguishing between legitimate concerns surrounding national security and trade. In addition to retaining defense relevance, successful commercial-military integration technology investments will be those that reflect marketplace realities and are used to leverage much larger transnational commercial investment activities. CMI technology investment policies must therefore be formulated to provide measured stimuli that are in harmony with existing market incentives and used to demonstrate the potential "synergies" that would yield benefits in both commercial and defense activities.

CONCLUSION: **Dependence on an integrated industrial base gives rise to new sorts of dangers to national security. Primary among these is the increased availability adversaries will have to technologies incorporated into U.S. military systems. In addition, a host of problems may result from the increasing proximity of commercial and military needs that will make defense expenditures a *de facto* part of the national welfare equation. The Department of Defense will need to improve its understanding of commercial technology and business developments in order to counter potentially threatening activities by**

transnational firms and to prevent the diversion of its resources for purposes other than national security.

While promoting CMI, DoD must remember that "unifying" the commercial and military industrial bases will produce an environment where commercial advances will become increasingly central to national security. Correspondingly, the diversion of national resources for defense may be seen less as a drag on overall economic growth and more as a requirement for commercial endeavor. The prevalence of this perception will correlate with the success of CMI—future difficulty in separating commercial costs and benefits from defense technology investments will begin to cast such expenditures as socially beneficial. At all costs, DoD must avoid being lured by arguments for investments which are peripheral to defense needs.

Therefore, to the extent that commercial technologies become more applicable to military purposes, commercial-military integration must be seen as having both benefits and risks for U.S. security. To succeed in a rapidly changing global marketplace, DoD must create for itself an unfettered and flexible acquisition and technology investment environment that is adaptable to revolutions in the nature of product and process technologies.

Even the way that national security issues are presented will have to be adjusted as the effects of closer ties between defense and commercial production emerge. For instance, arms exports have traditionally been used both as political "levers" as well as a way to spread development costs for domestic arms industries—every industrialized nation and many developing nations benefit from the arms trade in this manner. In the future we should expect commercial exports with defense applications to be promoted for both economic and national security reasons. Arms production has also been important to regional tax bases and political constituencies, primarily by offering a significant source of employment—as today evidenced by the reduction of U.S. military expenditures. It is not unreasonable to expect future national security arguments to be made in support of selected commercial activities—as already occurred in the debate over "critical technologies."

It follows that while defense industry globalization is today primarily a national security issue in the military sense, its economic and dual-use dimension force it into the national welfare equation. The reactive approach by the United States, reflected in the growing demands for trade protection by domestic industry and labor, represents "neo-mercantilist" urgings problematic for national security policies that must be founded in a world in which defense and commercial pursuits are closely aligned. This is particularly critical since the historical success of protectionist policies has been less than admirable. That is, while nations such as Japan have found merit in "infant industry" approaches to developing indigenous commercial capabilities, even they recognize that domestic industries must face "world-class" competition in order to succeed in the global marketplace. Without such direct challenges to the organization and conduct of business, firms tend to underachieve both domestically and internationally. Since defense production will come to rely much more significantly on commercial technologies and industrial capabilities in the future, the failure of U.S. industry to remain world-class will have a similar affect on U.S. military capabilities.

CONCLUSION: **In choosing dual-use investments, public policymakers must carefully consider the structure of the firms, industries, and markets which their programs are intended to influence. Such advice is not new. In the case of CMI, however, special attention must be given to the placement of and signals sent through government technology investments.**

In Part 2 of this paper we surveyed various techniques for choosing among technology investments and concluded that there is no "single best" approach to constructing a dual-use technology investment portfolio for the purposes of promoting CMI. This is in part due to the significant difficulties in comparing the attributes of different investment possibilities, as well as to the long time horizons which make it impossible to accurately predict their outcomes. Even retrospective assessments of prior technology investments are not always illuminating because of the myriad non-technological factors that may influence outcomes. We are thus led to rely on lessons from past investments to structure programs according to *a priori* beliefs in principles that will regulate their behavior and determine their performance—we invest according to *parables*.

Our discussions in Part 2 also illuminate difficulties which may be encountered in managing a large portfolio of technology investments. This is because the same issues in comparing the attractiveness of investment projects are raised when we attempt to measure their progress and ultimate impacts. As a result, the managers of an investment portfolio with a large number of projects are forced to abstract from specific characteristics and to rely on generalizations about their ultimate goals and utility. In this sense we are effectively managing technology as if it were an *icon*, where each project is accorded a simpler representation, itself a detail in a larger scheme.

Such "investment by parable and management by icon" suggests that success in promoting CMI with dual-use technology investments depends on the manner in which the government structures the selection of investments. That is, investments that fail to include the right mix of technical and management talent, commercial market astuteness, and understanding of military goals and needs begin with a disadvantage that is difficult if not impossible to overcome.

RECOMMENDATION: **There is a difference between dual-use technology investments and investments that will ultimately lead to commercial-military integration. Any successful long-term CMI strategy must seek to differentiate between what is potentially dual-use from a technological standpoint, and what is both commercially viable and militarily useful from both a technological and private marketplace standpoint. The following nine criteria are recommended as guidelines for choosing dual-use technology investments.**

1. General Defense Relevance

Dual-use technology investments must have a clear connection to future needs and requirements of the Department of Defense. *General defense relevance* pertains to the requirement that all CMI projects must further the cause of national security, either directly for military purposes, or indirectly through industrial base improvements which may be demonstrated as integral to providing for the national defense. There are limits to the applicability of dual-use for DoD missions. This point cannot be overstated—it is not the purpose of DoD to fund projects which cannot be demonstrated as linked to national defense missions—regardless of their potential economic benefits.

2. Attention to DoD Cost Drivers

Dual-use technology investments should target investments that promise to leverage significant cost savings for DoD. This *cost-reduction, rate-of-return criterion* is a corollary to so-called private rate of return. It focuses investments on the need to produce significant cost savings for national defense and emphasizes not only dual-use and co-production activities, but also personnel and training cost reductions. Approximately 50 percent of DoD's budget is in manpower. Derivative investments would result from an examination of the cost structure of current and future DoD weapons systems and the costs of those components which could be most affected by the introduction of new technologies. Attention to DoD cost drivers would also benefit commercial applications of technologies since cost is a primary commercial consideration.

3. Commercial Market Drivers

A *commercial market driver* exists when a commercial demand for a product or process coincides closely with a defense need. Dual-use technology investments should demonstrate strong linkages to future commercial markets, both in terms of the potential size of these markets and the nationality of firms likely to be major players in the markets. There should be strong economic justification. In particular, CMI will require that firms clearly see a commercial return on their investments if an integrated industrial base is to become a reality. Without strong *a priori* commercial interest the lure of non-dual use investments will lead the private sector to emphasize other opportunities. In particular, maximum flexibility must be maintained when defining military requirements.

4. Significant Technology Leveraging

To achieve desired defense-relevant goals, DoD should seek to *leverage the impact* of its dual-use technology investments by targeting areas in which there is clear under-investment by either the private sector, the public sector, or both. Expending DoD funds in areas where there are already large technology investments will have little leverage or pay-off. Therefore, investments should be made in domains where private sector interest is lacking because risk/reward ratios are too high or public sector investment has yet to be directed in earnest.

5. Critical Path Roadblocks

Dual-use investments should target specific technical challenges that are unlikely to be addressed by the private sector alone. Such challenges constitute a *critical path roadblock* because promising future technology developments are curtailed by the high cost of overcoming one or more technical challenges. In some cases such challenges will need to be targeted based on defense needs alone. However, we also demonstrated that what may begin as a military-unique investment may ultimately promote commercial markets by overcoming technical challenges where the private rate of return is low and results from technology investments are easily appropriated. Where appropriability or high social rate of return is an issue—essentially the creation of a public good—government investment or intervention is generally warranted.

6. Full Spectrum Industry Participation

Maximum impact from dual-use technology investments is most likely to vary directly with the number of participants in a development project. By *full spectrum* we mean the need to involve all parties with an interest in a project in a partnership or research alliance. This is important for two reasons: It is necessary to make sure that the industry leaders are involved to improve the chances for success. And full spectrum participation precludes giving one firm an advantage over another (maintains "safe" distance from commercialization/ productization). The use of R&D alliances as a means to diversify investment risk was briefly touched upon in this paper.

7. Portfolio and Cost Share/Capital Availability

A *portfolio* of dual-use investment projects with varying degrees of riskiness should be developed, and goverment support differentiated according to risk. There is a need to balance private rate of return with diversification of risk in a portfolio. Where risk is low, private sector investors should carry the primary burden for funding a project with commercial potential and military utility. Where risks are high and capital availability is an issue, there is a need to determine whether these circumstances derive from appropriability concerns or lack of information about opportunities. The level of support from the government and the quality of contributions from the private sector should then be adjusted according to the goals, anticipated returns, and risks of the planned investment.

8. Process Technology Focus

Process technologies are key to industrial base integration and should be a focus of dual-use investments. The essence of an integrated commercial-military industrial base is the ability to co-produce commercial and military items. But because international competition is leading to global out-sourcing, maintainance of a world-class industrial base necessitates that domestically based, U.S. firms maintain a competitive edge both in product and in process technology. To ensure that CMI is achieved and does not leave the U.S. “hostage” to foreign suppliers, DoD must promote cost-efficient process technologies that afford it and the commercial world distinct advantages over existing approaches to production. *All* dual-use technology investments should therefore stress the importance of process technology development.

9. Social Rate of Return and Pervasive Impact

Dual-use technology investments should seek to maximize social benefits, particularly as a result of external effects from projects as discussed in Chapter VI. A measurable, beneficial, direct impact on U.S. firms and national security should result from ultimate maturity of the technology development to be pursued. Beneficial impacts on firms include the creation of jobs, improvement in productivity, and increased profitability. Beneficial impacts on national security include reductions in weapon system costs, technological "leap-frogging" of foreign competitors' capabilities, and demonstration of co-production of military and commercial products. Indirect beneficial effects should also accrue to U.S. firms both upstream and downstream from products or processes expected to result from the technology development efforts.

RECOMMENDATION: **In order for dual-use technology investments to be successful, there is a need to improve DoD's ability to gauge the commercial attractiveness of such investments. To improve the prospects for successfully achieving CMI, DoD should assemble an in-house commercial assessment capability for use in determining the potential commercial viability of dual-use investments.**

As we move toward an integrated industrial base, there will be a growing need for commercial expertise within DoD to identify, recommend, and select investments appropriate to CMI. Beyond the Cold War technology-based approach to investment for the military, there is a need to address private and social rate of return characteristics as well. Unfortunately, such commercial financial and economic expertise is not yet available within DoD.

Immediately, DoD should seek to assemble a team of experts to assess and advise on the commercial viability and broader social impacts from proposed dual-use investments. To avoid conflict of interest issues, such a team could be drawn from retired executives in the commercial world, Federally Funded Research and Development Centers, and panels of the National Research Council.

Experts in finance should be recruited before investments are made to help examine the types of firms likely to be attracted by dual-use opportunities. These same experts could also assist with the oversight of investments through periodic progress reviews.

Experts in economics, and more specifically industrial organization, could be used to examine the likely market consequences of dual-use investments prior to committing to a project. In addition, they could look for externalities, spillovers, and linkages from these investments that would offer prospects of high social rates of return. Throughout project execution they would continue to monitor markets both domestically and internationally.

RECOMMENDATION: **Consideration of the role of the global marketplace and efforts to address it will become central to the success of CMI. It cannot be over-emphasized that world-class commercial and dual-use industrial capabilities are the only means to an affordable military based on an integrated industrial base. Cross-border alliances, including consortia and partnerships, appear to be central to facilitating access to foreign technologies and capabilities that may reduce the cost of pursuing military applications. Such alliances take considerable time to coalesce, however, and DoD must begin to send "signals" to potential private sector investors with sufficient lead time for their formation. With greater reliance on the private sector, there is a need to promote commercial-military business alliances that seek to incorporate foreign technical and management innovations to speed the maturation of CMI investments and foster globally competitive U.S. commercial firms.**

In Chapter III great emphasis was placed on developing a global strategic perspective necessary to cope with CMI. This perspective is essential for keeping U.S. security world-class since the underlying dual-use industrial base must also be world-class. In essence, DoD must avoid committing to projects that do not have the potential to help participants excel in the global marketplace.

To realize such a strategy, dual-use investments must combine the best of both the commercial and defense "worlds." For instance, European and U.S. experience suggests that strategic alliances and appropriately structured prime/supplier relationships are important because of the complex nature of modern weapon systems. Alliances and consortia are also rapidly becoming the norm for commercial endeavors, and have demonstrated significant advantages in promoting enterprise agility, reducing costs, and delivering quality.

In order for successful alliances useful in pursuing CMI to be formulated, government and industry must begin to align their interests to develop both tactical plans and strategic visions. The problem with "cobbled-together" alliances is that they are not likely to survive long enough to realize the benefits of technology investments. Furthermore, even if commercialization does result, defense relevance may be lost if the defense partner departs from a team, or alliance dissolution leaves further development in the hands of commercial partners.

We note that such alliances should seek to take advantage of foreign technology developments where national security is not compromised. This would include consideration of Japanese and German firms as part of CMI alliances if they could be demonstrated to have a significant contribution to make. Also, former Eastern bloc nations should not be excluded from CMI alliances if they have particular technical capabilities that could be pursued and developed more cheaply than starting from scratch.

APPENDIX A

SOURCES OF GROWTH

Table A-1. Contributions of the Different Sources of Growth (Percent)

		Time Period With Quality Adjustment					Without Quality Adjustment				
	Time Period	*Capital*	*Tech. Progress*	*Subtotal*	*Labor*	*Scale*	*Capital*	*Tech. Progress*	*Subtotal*	*Labor*	*Scale*
Abramovitz 1956	1869–1953						22%	48%	70%	33%	
Solow 1957	1901–1949						21%	51%	72%	24%	
Kendrick 1961	1889–1953						21%	44%	65%	34%	
Denison 1962	1909–1929	26%	10%	36%	54%	10%	26%	33%	59%	32%	10%
	1929–1957	15%	20%	35%	54%	12%	15%	58%	73%	16%	12%
Denison 1967	1950–1962	25%	32%	57%	34%	9%	25%	47%	72%	19%	9%
Kuznets 1971	1889–1929						34%	34%	68%	32%	
	1929–1957						8%	78%	86%	14%	
	1950–1962						25%	56%	81%	19%	
Jorgenson and Griliches 1972 reply	1950–1962	49%	30%	79%	21%		40%	51%	91%	8%	
Kendrick 1973	1948–1966						21%	56%	77%	24%	
Denison 1979	1929–1976	15%	30%	45%	46%	9%	15%	50%	65%	26%	9%
Denison 1985	1929–1982	19%	26%	45%	46%	9%	19%	46%	65%	26%	9%
Jorgenson, Gollop & Fraumeni 1987	1948–1979	47%	24%	71%	30%		12%	69%	81%	20%	

SOURCE: Michael J. Boskin and Lawrence J. Lau, "Capital, Technology, and Economic Growth," *Technology and the Wealth of Nations*, Stanford University Press, Stanford, California, 1992, p. 32.

NOTE: The capital and labor shares are assumed to be fixed by some authors and variable by others. In studies in which the factor shares are variable the average share over the sample period is used in our calculations. Thus, the contribution from the different sources may not sum to exactly unity because of approximation errors.

APPENDIX B

CASE STUDY RESULTS

1975 MANSFIELD RESULTS

Table B-1. Social and Private Rates of Return From Investment in Seventeen Innovations[1]

Innovation	Rate of return (percent)	
	Social	Private
Primary metals innovation	17	18
Machine tool innovation	83	35
Component for control system	29	7
Construction material	96	9
Drilling material	54	16
Drafting innovation	92	47
Paper innovation	82	42
Thread innovation	307	27
Door control innovation	27	37
New electronic device	Negative	Negative
Chemical product innovation	71	9
Chemical process innovation	32	25
Chemical process innovation	13	4
Major chemical process innovation	56	31
Household cleaning device	209	214
Stain remover	116	4
Dishwashing liquid	45	46
Median	56	25

[d] Based on investment of entire industry. See Section VI.

1 Mansfield, Edwin, et al., "Social and Private Rates of Return From Industrial Innovations," *Quarterly Journal of Economics.*

1978 ROBERT R. NATHAN, ASSOCIATES, RESULTS

Table B-2. Summary Results of 20 RNA Case Studies[2]
(in percent)

Innovation Number	Private IRR Base Case	Private IRR Low	Private IRR High	Social IRR Base Case	Social IRR Low	Social IRR High	Social IRR Minus Private IRR (Base Case)
1	54.3	50.1	58.0	59.7	55.8	63.6	5.4
2	neg.	neg.	a	47.0	35.0	65.0	47.0[b]
3	27.7	23.6	34.2	neg.	neg.	neg.	(27.2)[b]
4	44.0	37.0	52.0	44.0	37.0	52.0	0.0
5	157.0	100.0	196.0	157.0	100.0	196.0	0.0
6	50.0	11.0	68.0	20.0	neg.	36.0	(30.0)
7	38.0	29.0	48.0	38.0	29.0	48.0	0.0
8	56.0	51.0	62.0	105.0	99.0	112.0	49.0
9	neg.	neg.	26.0	0.0	0.0	0.0	0.0[b]
10	34.0	28.0	39.0	140.0	112.0	194.0	106.0
11	neg.	d	d	163.0	60.0	287.0	163.0[b]
12	70.0	59.0	96.0	173.0	151.0	289.0	103.0
13	11.9	4.2	21.4	neg.	neg.	4.4	(11.9)[b]
14	17.9	–	–	42.9	8.9	47.7	25.0
15	124.2	123.4	124.6	119.5	d	d	(4.7)
16	76.2	75.2	80.3	79.5	77.1	86.8	3.3
17	83.0	79.0	84.0	90.0	85.0	91.0	7.0
18	2.6	(22.4)	2.6	150.5	59.3	150.5	147.9
19	7.0	d	d	26.0	20.0	26.0	19.0
20	neg.	d	d	371.0	280.0	425.0	371.0[b]
Median: 18 cases[e]		36.0			70.0		4.4[c]
Median: 20 cases		36.0			70.0		6.2[c]

a Maximum of approximately 22,000 percent.
b Approximation; assumes negative values equal to zero.
c Median difference, not difference of medians.
d No meaningful difference.
e Excludes two cases from a regulated industry (numbers 19 and 20).

2 National Science Foundation, Washington D.C., *Net Rates of Return on Innovations*, Executive Summary, October 1978.

1978 FOSTER ASSOCIATES< RESULTS

Table B-3. A Survey on Net Rates of Return on Innovations[3]

Innovation		Rate of Return (percent)	
		Social	Private
Industrial Products	A	62	31
	B	negative	negative
	C	116	55
	D	23	0
	E	37	9
	F	161	40
	G	123	24
	H	104	negative
	I	113	12
	J	95	40
	K	472	127
	L	negative	13
Consumer Products	M	28	23
	N	62	41
	O	178	148
	P	144	29
Industrial Processes	R	103	55
	S	29	25
	T	198	69
	U	20	20
Median		99	24

3 National Science Foundation, Washington D.C., *A Survey on Net Rates of Return on Innovations*, Volume II, Summary and Analysis, May 1978.

APPENDIX C

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APPENDIX C
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13. ABSTRACT *(Maximum 200 words)*

Reductions in the size of DoD budgets coupled with rapid technological change in the commercial world suggest that dramatic shifts in the strategies for producing and acquiring weapons systems are needed. The Department of Defense must move towards integrating the commercial and military industrial bases which grew apart during the Cold War in order to capture the technological benefits and production efficiencies of the commercial world. This must be done as part of a paradigm shift which includes acquisition reform as well as revolutions in the research, design, and development of weapons systems. To be successful, the Department must pay close attention to how the private sector operates, and seek to modify DoD's method of "doing business" to more greatly harmonize with commercial practices.

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